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Migration of Adult Chinook Salmon and Steelhead Past Dams and Through Reservoirs in the Lower Snake River and Into Tributaries - 1993

Annual Report for 1993

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by

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for

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Acknowledgments

Several people and agencies contributed to the success of the third year of the study of adult salmon and steelhead passage in the Snake River basin. The Corps of Engineers and Bonneville Power Administration provided the funding for the study. Teri Barila of the Corps' Walla Walla District was an involved and helpful project officer. Marc Petersen, Michelle Feeley, Dinesh Kumar, Pritpal Gill, Mohammed Khatouri, Jed Volkman, Brian Hastings, Jay Nance, Erik Odenborg, Steve Lee, and Catherine Smith assisted in processing the data and helped with the fish trapping and tagging. Idaho, Oregon, and Washington personnel monitoring the fisheries and spawning grounds aided in the recovery of tagged fish. Hatchery personnel in all three states aided by collecting tags and transmitters from fish entering the various hatcheries. Fish counters at the four dams kept counts of the groups of spaghetti-loop tagged steelhead released for the zero-flow study.

Table of Contents

Abstract

A study of the upstream migration of adult spring and summer chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* past the four lower Snake River dams, through the reservoirs, and into the tributaries of the Snake River drainage was initiated in 1991 and continued in 1992 and 1993. The objectives were to evaluate the effect of spill, powerhouse operation, and flows on the rates of passage of the fish at the dams, migration through the reservoirs, the fishway entrances used, fallback at the dams, and movements into the tributaries upstream from the reservoirs.

In 1993, 1,171 spring and summer chinook salmon and 884 steelhead were trapped and released with transmitters in the south shore ladder at John Day Dam and monitored as they continued their migration to the spawning areas or hatcheries in the Snake River basin to assess migration rates and success. Spaghetti-loop and VI (visual implant) tags were placed on 1,994 steelhead trapped at Ice Harbor Dam and released upstream from Ice Harbor Dam during four periods of normal or zero flows at night from the three upper dams to assess the effect of reduced flow at night on migration.

Fishway fences installed adjacent to the north powerhouse entrances at Little Goose and Lower Granite dams in 1991 to reduce fallout from the fishways were evaluated in 1992 and appeared to be ineffective in reducing the overall fallout rate at those entrances. For 1993, the fence at Lower Granite Dam was removed so comparisons could be made with and without the fence. Special scanning receivers and underwater antennas were installed at the entrances to the fishways and within the fishways at all four of the lower Snake River dams early in 1993 to evaluate fishway use by chinook salmon and steelhead under various flow, spill, and powerhouse operations.

Success of passage for the spring and summer chinook salmon can be measured in several ways. Based on counts of all adult chinook salmon passing through the fish ladders, 92% of the fish counted at Ice Harbor Dam were later counted at Lower Granite Dam in 1993, a higher percentage than in 1992 (83%). Salmon outfitted with transmitters survived the passage from the

top of Ice Harbor Dam to the top of Lower Granite Dam at a rate of 90% in 1993 and 85% in 1992, rates similar to the untagged fish migrating up the river. Passage success was not affected by chinook salmon falling back over the dams in 1993. A total of 19 fallbacks (some multiple by individual fish) among the salmon with transmitters were recorded at the four dams.

Success of passages of steelhead with transmitters from the Ice Harbor Dam tailrace to the forebay at Lower Granite Dam and the upper end of the Lower Granite pool were an estimated 81.3% and 78.7%, respectively, in 1992 (87% and 75% in 1991) based on fish known to have passed through the ladder at Lower Granite Dam.

In 1993, the maximum survival of chinook salmon with transmitters migrating to natal streams or hatcheries was 77%, versus estimates of 63% in 1992 and 54% in 1991. There was evidence in 1992, as in 1991, that some fish apparently destined for hatcheries migrated to the vicinity of the hatcheries, but did not enter the hatcheries. There was little evidence of such behavior in 1993.

The median times required for chinook salmon to pass from the tailraces to the forebays of each lower Snake River dam ranged from 0.6 to 1.2 d/dam in 1993, versus ranges of 0.2 to 1.3 in 1992 and 0.7 to 5.4 in 1991. Migration rates through the reservoirs ranged from 31 to 65 km/d, based on 0.8 to 1.9 median days per reservoir. The median rates of migration in the free flowing rivers ranged from 10 to 30 km/d in 1993, rates that were similar to those in 1991 and 1992.

The distribution of spring versus summer chinook salmon in the Snake River basin varied by tributary. Timing of the migration in 1993 was closer to normal than in 1992. The separation between the spring and summer runs of chinook salmon at Ice Harbor Dam appeared to occur near the usual separation date of 11 June in 1993, and was probably related to the higher flows and turbidities in the latter year.

The relative distribution of spring and summer chinook salmon with transmitters into the tributaries of the Snake River basin in 1993 was 5% into the Tucannon River, 21% into the Clearwater

River, 4% in the Snake River proper upstream from Lewiston, 11% into the Grande Ronde, 8% into the Imnaha, and 51% into the Salmon rivers.

In 1993, 251 steelhead were trapped and released with transmitters in the summer, and 633 were released in the fall at John Day Dam. Twenty-five percent of the fish released in summer and 41% of the fish released in the fall were recaptured in the trap at Lower Granite Dam. Of the 884 steelhead released at John Day Dam, 458 (52%) were last reported in the Columbia River or its tributaries exclusive of the Snake River, 211 (24%) were found or recaptured in the Snake River downstream from Lewiston, 123 (14%) were located in the Clearwater River basin, 22 (2%) ended up in the Grande Ronde basin, 64 (7%) were last reported in the Salmon River basin, and 2 fish were last located in the Imnaha River.

Steelhead released at John Day Dam with transmitters in the summer or fall of 1993 that passed over Lower Granite Dam in 1993, had median passage times of less than a day at John Day Dam, 4-5 d from the top of John Day to the top of McNary dams, 1-2 d from McNary to the tailrace of Ice Harbor dams, and 0.7 to 1.7 d to pass each of the four lower Snake River dams. The rates of migration through the reservoirs, based on median days to pass, by steelhead in the fall of 1993 were about half (30 km/d) that of chinook salmon in the spring. Median migration rates of steelhead in the fall in the free-flowing rivers upstream from the Lower Granite pool were variable and relatively slow (generally less than 11 km/d), as expected, because steelhead stop and spend the winter in the rivers.

In the spring and summer of 1993, chinook salmon with transmitters were monitored with new instantaneous-scan receivers as they approached, entered, and passed through the fishways at the four lower Snake River dams to evaluate passage into and through the fishway. Salmon approached the entrances to the fishways in less than 2 hours (median time) after entering the tailraces. Median times to first entries into the fishways were less than 4.5 hours, and times to pass over the dams were less than a day. The median times to first entry were similar for no spill, low spill, and medium spill conditions at each dam. Fewer fish passed the dams during medium spill conditions, and no

salmon, that could be used in the rate calculations, passed during high spill conditions. Most of the salmon first approached the dams along the south or north shores or at the mid river end of the powerhouses. Salmon made several approaches to the entrances. The south shore, north powerhouse (at Lower Granite Dam), and north shore entrances were the openings most used by salmon for first entry into the fishway, and those entrances had the highest net entry rates.

The fishway fence put in place at Little Goose Dam to prevent high exit rates from the north powerhouse entrances, seemed to have the opposite effect, because many salmon, like steelhead, were found to move downstream in the powerhouse collection channel, and then were guided into, instead of away from, those openings. At Lower Granite Dam the fishway fence was removed prior to the 1993 migration and one of the north powerhouse entrances had more exits than entries by salmon, while the other entrance had more entries than exits during the spring.

The zero-flow test was continued in 1993, with 1,994 steelhead released with spaghetti-loop and visual-implant tags at Charbonneau Campground upstream from Ice Harbor Dam during the first 5 d of four two-week periods starting in early September and continuing into November. The patterns of movement by steelhead in the four groups through the lower Snake River, as measured by counts of tagged fish at the dams, recaptures at the Lower Granite adult trap, and records of fish with transmitters, were similar to those observed in both 1991 and 1992. More of the fish in the second and third groups proceeded up the river than in the first and fourth groups. Water temperatures, high at first and then low by November, appear to affect the timing and proportion of steelhead moving past the dams during the fall more than the flows at night. Migration rates of steelhead with transmitters through the three reservoirs affected by the zero or normal flows at night did not differ significantly in all three years.

Introduction

Adult spring and summer chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* migrating to their natal streams in the Snake River basin must pass over eight dams and through as many reservoirs, four of which are in the lower Snake River. Losses of adults and delays in migration at each hydroelectric project must be kept to a minimum if we hope to succeed in maintaining the native runs of fish and achieve the Northwest Power Planning Council (NPPC) goal of doubling the abundance of fish in the future.

These studies address concerns of the Corps of Engineers (Corps) and section 603 of the Northwest Power Planning Council's 1987 Columbia River Basin Fish and Wildlife Program, and the need to conduct studies to determine the effects of reduced and instantaneous flows on adult fish. Also included in the Program was the need to study fishway entrance use to determine the best flows and operating conditions.

The study was developed in consultation with Corps personnel, and in response to the high priority assigned to adult passage research in the Snake River by the Fish Research Needs and Priorities subcommittee of the Corps of Engineers' Fish Passage Development and Evaluation Program. The NPPC outlined adult passage problems in 1988 and urged that research be undertaken. In 1989, the Fish Passage Center recommended as top priority for the Corps' Walla Walla District, a study to verify which spill patterns at the Snake River dams will result in the least fallback.

Research has been conducted in the past by personnel of the Corps, Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU), Oregon Department of Fish and Wildlife (ODFW), and National Marine Fisheries Service (NMFS) to evaluate passage rates, entrance and fallout in the passage facilities, fallback over the dams, spill and tailrace flow patterns, and migration rates with reduced nighttime flows at the Snake River dams. Facilities and operating procedures were modified as a result of earlier studies, and studies are needed to determine if the changes will result in the desired improvements. The studies by Turner et al. (1983, 1984) were conducted during only a part of the migration season and with an incomplete range of flow conditions, and they recommended further study.

Additional studies were needed to better define: (1) the effects of an extended period of zero flows at night on the passage of adult fish over the dams and through the reservoirs, (2) the effect of spill configuration on the entry of fish into the fishway and the passage rate, (3) the rate of fallout from fishway entrances with a special fishway fence in the powerhouse collection channel, (4) the rate of fallback over the dams with various flow conditions, and (5) the distribution, migration rates, and survival of fish after they leave Lower Granite Dam.

Objectives for the studies conducted in 1993 were as follows:

1. Determine the effects of zero flow at night on migration rates, and on the proportion of adult steelhead passing each dam, entering the fisheries, and returning to hatcheries.

2. Determine the effects of quantity of spill and the patterns of spill on the rate of passage, and fishway entrance use by adult spring and summer chinook salmon at the four lower Snake River dams.

3. Evaluate the effectiveness of a fence installed in the fishway at Little Goose Dam for reducing the rate of fallout by adult salmon and steelhead at the north powerhouse fishway entrances.

4. Assess the fishway entrance preferences of adult salmon and steelhead at Lower Granite and Little Goose dams under various conditions of flow, spill, and powerhouse operation.

5. Assess the rate of adult salmon and steelhead migration up the lower Snake River under various, normally occurring conditions of flow, spill, powerhouse operation, and season of the year.

6. Assess the rate and route of fallback adult salmon and steelhead over or through the lower Snake River dams under various conditions of spill, flow, powerhouse operation, and season of the year.

7. Determine the timing of migration, migration rates, distribution of fish, and survival rates of salmon and steelhead after they leave Lower Granite Dam.

The area of study extended from Bonneville to Priest Rapids dams on the Columbia River, the Snake River from the mouth of the river upstream to Hells Canyon Dam, all the major Snake River tributaries, and at hatcheries where tagged fish were recovered (Figure 1). In a companion project funded by the mid Columbia Public Utility Districts, salmon captured and released at John Day Dam with transmitters were monitored at the mid Columbia River dams by NMFS personnel. Trapping and outfitting of the fish with transmitters was shifted to John Day Dam in 1993 to obtain fish destined for both the Snake River and the mid Columbia River. Releasing the tagged fish at John Day Dam also provided the opportunity to evaluate passage in the Snake-Columbia confluence area with fish that had likely recovered from trapping and tagging and behaved normally as they passed through the confluence area.

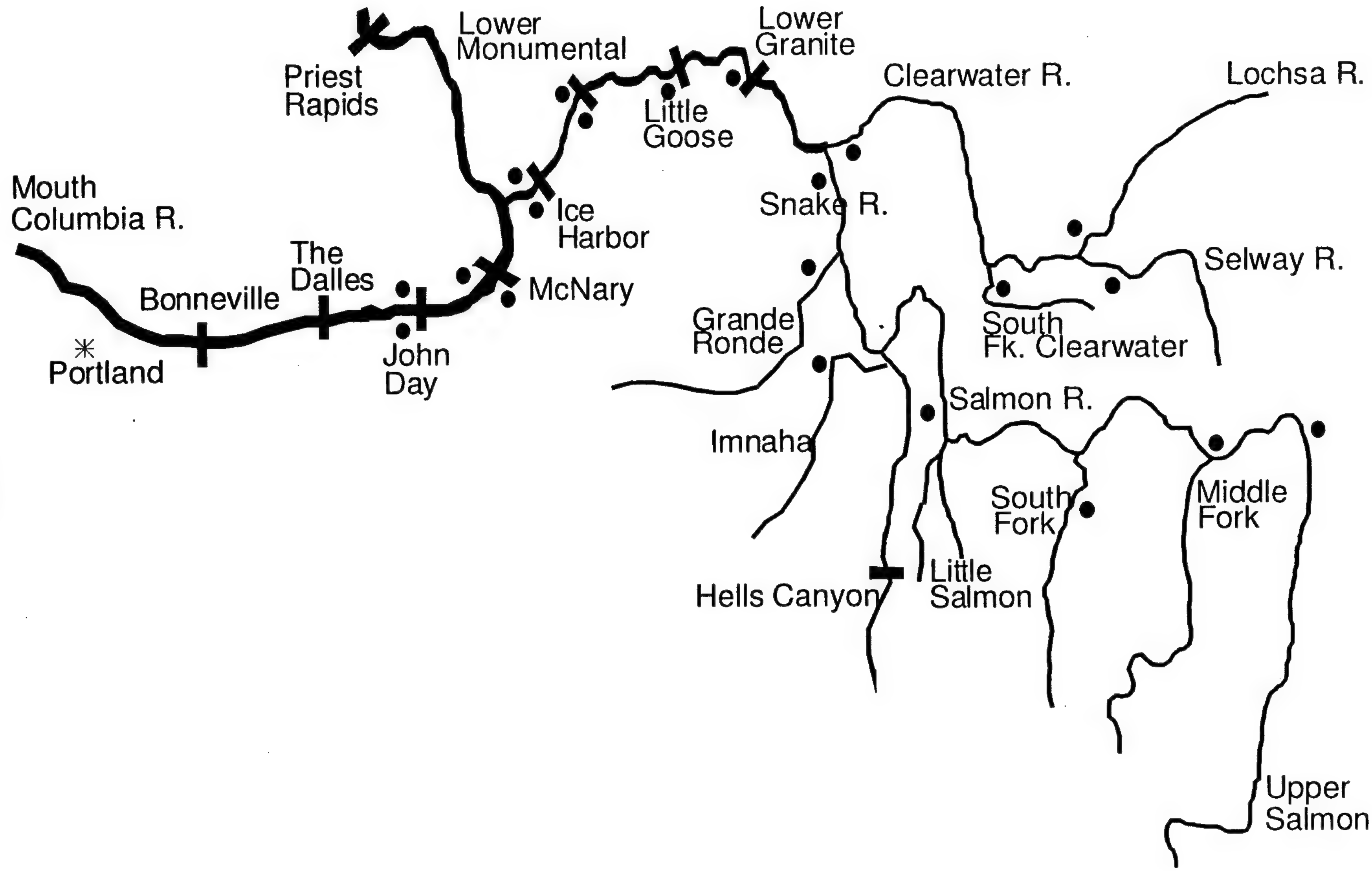


Figure 1. Map of the Columbia and Snake river basins with the location of dams and fixed-site receiver stations (solid circles) used to monitor the upstream migration of adult chinook salmon and steelhead in 1993.

Studies to assess migration rates and passage success of adult spring and summer chinook salmon and steelhead at the lower Snake River dams and into the tributaries in 1993 were conducted with fish captured, outfitted with radio transmitters, and released in the south ladder at John Day Dam (Figure 1). Steelhead tagged with spahgetti-loop tags for the zero-flow study were captured at Ice Harbor Dam, as in past years, and released at Charbonneau Campground about 2 km upstream from the dam. Radio transmitters were placed in 1,171 spring and summer chinook salmon and 884 steelhead to monitor their passage at the dams and into the tributaries, to assess rates of migration, time to pass each dam, the number that fell back at each dam, distribution of fish into the tributaries, and the proportion that completed migrations to spawning grounds or hatcheries. Spaghetti-loop tags were attached to 1,194 steelhead during the fall to evaluate the effects of zero flow at night on migration rates and passage success.

The influence of spill on migration rates, fishway entrance preferences, and fallback was evaluated in 1993 for the first time since this study began. Volume of the spring runoff was large enough to cause spill at all of the lower Snake River dams. The duration of the spill period and quantity of water spilled varied by dam and was dependent on flow, the number of turbines that could be operated, and power demand.

The results of the radio telemetry studies in 1993 have been organized into several segments: migration rates, passage success, and distribution of chinook salmon; fishway entrance use and passage by chinook salmon; spill pattern tests with chinook salmon; migration rates, passage success, and distribution of steelhead; and the effects of zero flow at night on steelhead migrations. The report on chinook salmon movements in 1993 includes the records of movements for chinook salmon obtained from April through October 1993. The reports on steelhead movements are also mostly complete, and include fish tagged and released in the summer and fall of 1993 with recovery data through the spring of 1994. The analyses of fishway entrance use and passage by steelhead in 1993 has not been completed and will be included in the final report.

Chinook Salmon - 1993 Migration Rates, Passage Success, and Distribution

Methods

The upstream migration of adult chinook salmon was monitored in 1993 by releasing fish with radio transmitters at John Day Dam on the Columbia River (RKM 346.9) and monitoring their migrations at John Day and McNary dams on the Columbia River and at each of the four lower Snake River dams. Movements of fish into the major tributaries were monitored using fixed-location receivers and mobile tracking receivers, and with recaptures of fish at traps, hatcheries, and recoveries from spawning grounds. The fixed-location receivers and associated antennas were installed at the dams and mouths of major tributaries by the spring of 1993 before the expected passage of radio-tagged fish.

Fixed-location SRX-400 sequentially scanning receivers were installed 1.5 to 2.7 km downstream from each of the four lower Snake River dams with two antennas at each site to broaden the reception field, to determine the direction of movement, and to determine when fish entered the tailrace area of each dam. Digital-spectrum processors (DSP) linked to SRX receivers were installed at the top of each fish ladder to determine when fish left the tops of the fishways. DSP/SRX receivers were also located on the powerhouse decks of each Snake River dam (with up to four underwater antennas connected to each receiver) at various fishway entrances, and in the fishway collection channel (Figure 2) to determine when fish approached the dam at a fishway entrance, had entered the fishway, and their movements within the fishways.

Three pickup trucks were outfitted with 4-element Yagi antennas, that could be rotated from within the cab, and SRX receivers to track fish with transmitters in areas not covered by fixed-location receivers. A boat was also set up for mobile tracking, primarily in the Columbia River upstream from the mouth of the Snake River. Once the fish began to move upstream beyond the Lower Granite pool and into the tributaries, mobile tracking was initiated on a schedule that included checking streams with road access every three weeks or less. Mobile tracking in the tributaries continued into September until the chinook salmon had spawned and died.

During the 1993 spring and summer chinook salmon runs, 1,171 adult fish (jacks were not tagged) were outfitted and released with radio transmitters at John Day Dam. We began capturing fish and outfitting them with transmitters on 19 April and released the last fish on 29 July 1993 (Figure 3). Turbidity of the Snake River in the spring of 1993 was higher (0.6 to 3.0 feet secchi disk visibility) than in 1992 because of the larger runoff. Secchi disk visibility at John Day Dam ranged from 2 to 4 feet during much of the runoff period (Figure 3).

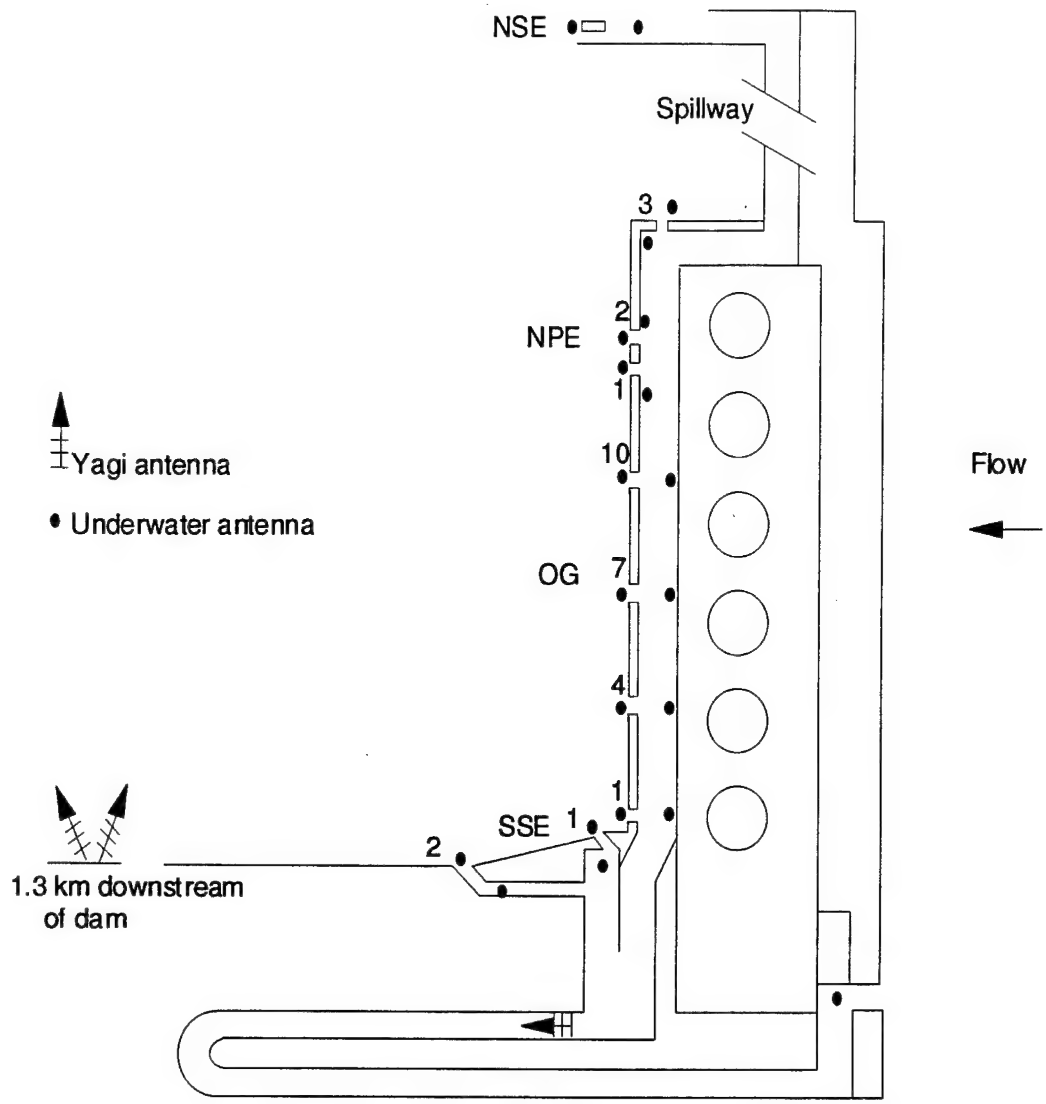


Figure 2. Drawing of a Snake River dam with locations of north shore (NSE), north powerhouse (NPE), orifice gate (OG), and south shore (SSE) entrances to fishway and antennas in the spring of 1993.

Of the 1,171 chinook salmon released with transmitters, 746 (63.7%) were released from 19 April to 5 June (presumably spring chinook salmon) and 425 (36.3%) were released from 6 June to 29 July (presumably summer chinook salmon) (Figure 3). Based on counts compiled by the Fish Passage Center, 55,552 adult spring chinook and 17,491 adult summer chinook salmon were counted at John Day Dam in 1993, with spring chinook salmon making up 76.1% of the total. Almost 64% of the chinook salmon we outfitted with transmitters in 1993 were tagged by 5 June.

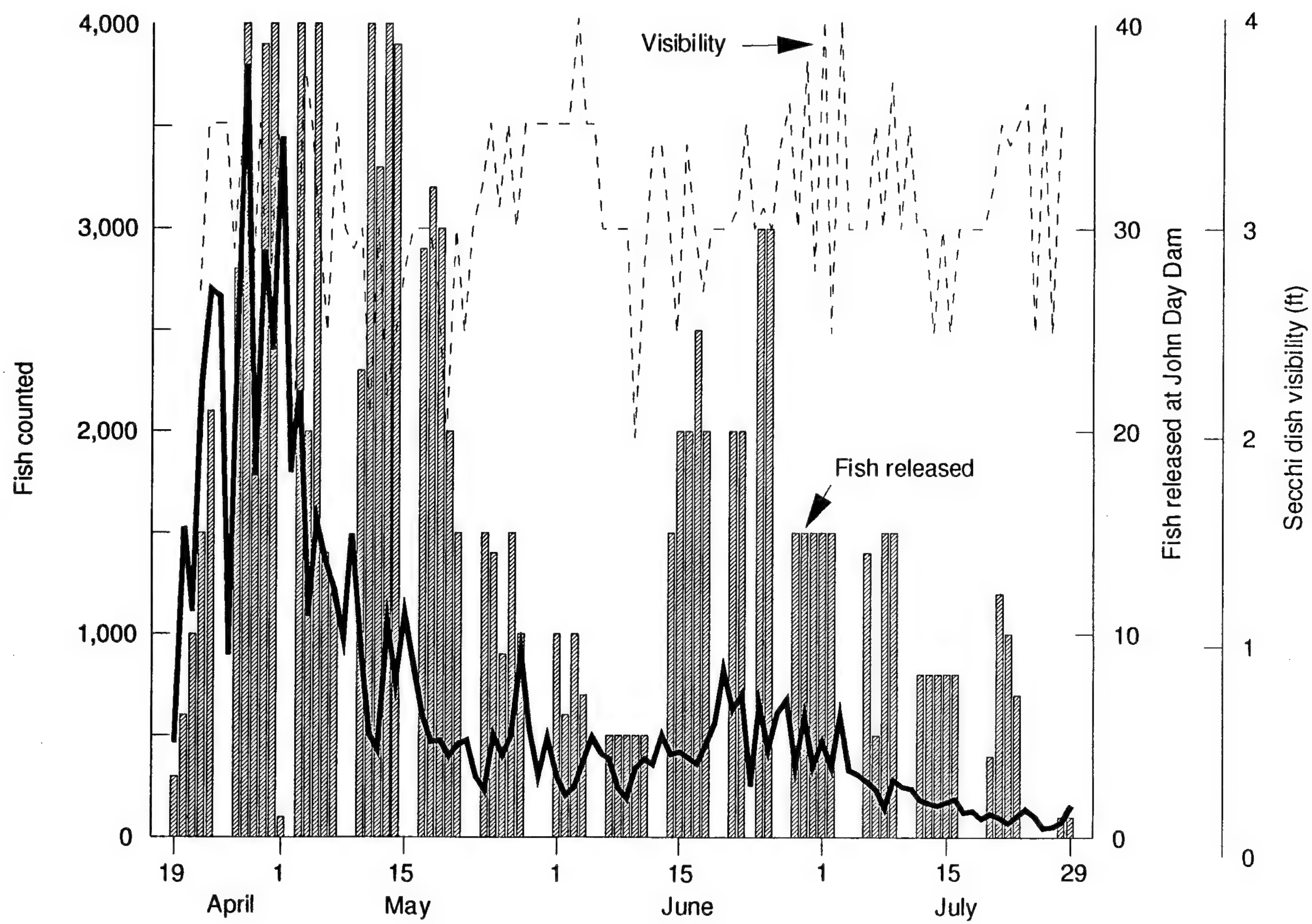


Figure 3. Daily counts of chinook salmon at John Day Dam, number of fish released with transmitters, and secchi disk visibility in the forebay of the dam in 1993.

The radio transmitters and receivers used in 1993 were manufactured by Lotek Engineering Inc., of Newmarket, Ontario, Canada and Yagi antennas by Cushcraft. The transmitters (80 mm X 16 mm) emitted a digitally coded signal every 5 seconds that could be interpreted by the receiver as a unique numeric code and recorded in a data bank along with the channel (frequency of the transmitter), relative power of the signal, antenna receiving the signal, date, and time. There were eight data banks in the receiver that could store a total of about 64,000 records. The receiver data banks were downloaded as files in a portable computer every 1 to 4 weeks depending on the location and fish activity at the site. Receiver reliability was high in general, with few gaps in the data resulting from loss of electric or battery power, or from receiver malfunction (Figure 4).

Chinook salmon outfitted with transmitters (inserted into the stomach through the mouth) in 1993 ranged in size from 64.0 cm to 110.0 cm fork length, a size range that included fish that had spent two or three years in the ocean. All of the hatcheries with predominantly spring chinook salmon (Rapid River, Lookingglass, Kooskia, and Dworshak) had more two-ocean than three-ocean fish in 1993 (Figure 5). In the hatcheries with more summer chinook salmon (South Fork/McCall, Pahsimeroi, and Sawtooth), three-ocean fish made up a large part of the fish returning in 1993.

In addition to the radio transmitter, all fish released were tagged with a numbered visual implant (V-I) tag placed in the clear tissue posterior to the eye, and a coded-wire tag inserted in the muscle near the dorsal fin. The V-I tag was used as a backup means of identifying fish released with transmitters, and the coded-wire tag was used to trip the detector at the adult trap in the ladder at Lower Granite Dam.

The usual trapping and tagging operation started at about 0800 hour each morning by lowering the bottom of the denil fishway into the water at the downstream end of the south ladder at John Day Dam (downstream from the counting window) and sealing off other migration routes up the ladder. Fish were then forced to swim up the denil where they could be observed and either selected for tagging or allowed to continue their migrations. Fish that were suitable for tagging with a transmitter were diverted from the denil into a tank with anesthetic (MS-222). When the fish were anesthetized, they were measured, sexed, examined for marks and injuries, a transmitter was placed in their stomach, they were tagged with VI and coded-wire tags, and placed in a recovery pen in a pool of the ladder adjacent to the denil fishway.

After recovery from tagging and the anesthetic, the fish were released (generally less than 1 hour) by opening the recovery pen and allowing the fish to exit and continue their migrations. Regurgitated transmitters found in the pen were reused in other fish and the records changed to indicate which fish had regurgitated a transmitter.

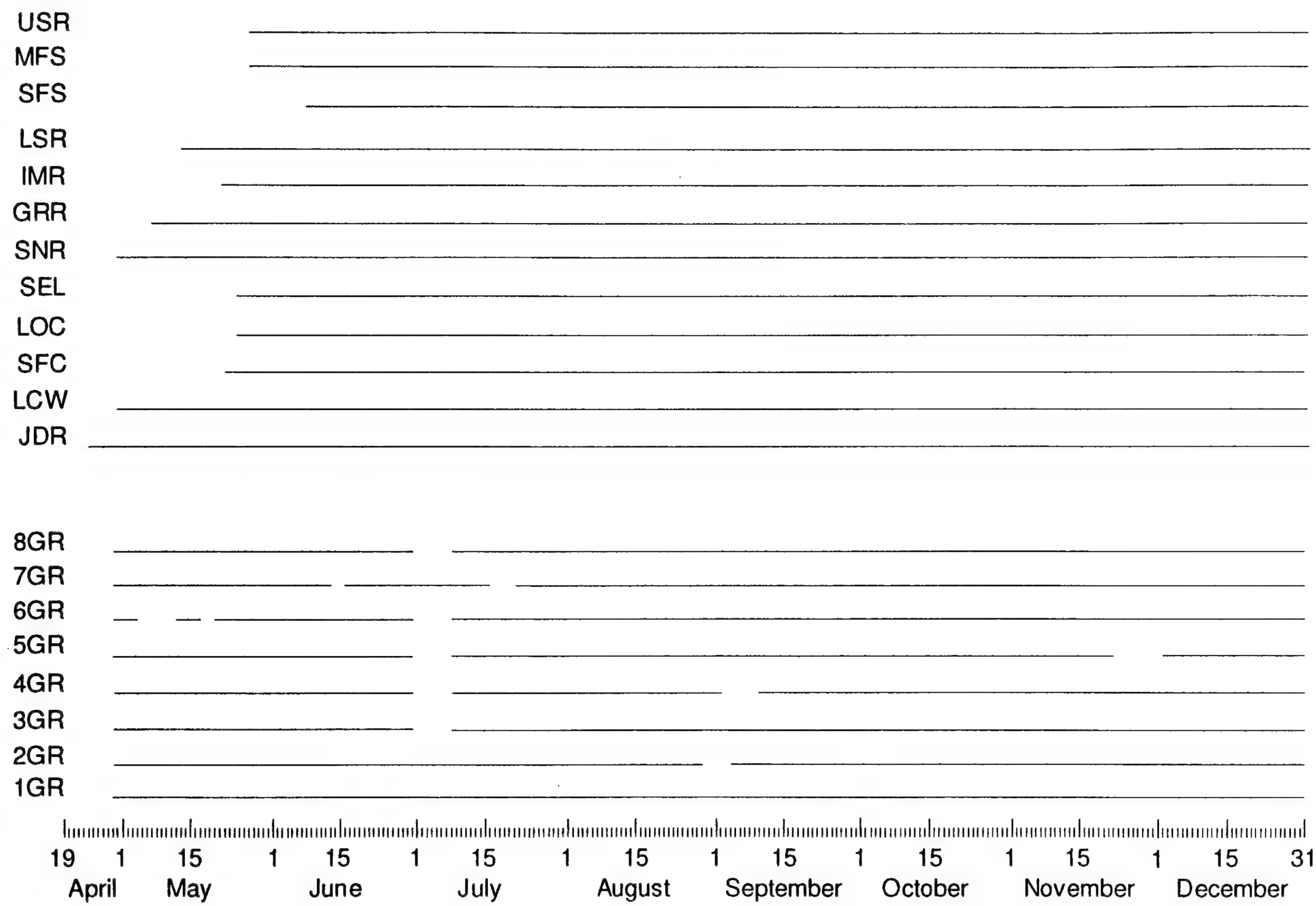


Figure 4. Diagram to illustrate periods of operation of fixed-location receivers at dams and at sites near the mouths of tributaries in the Columbia and Snake river basins in 1993. Breaks in lines represent periods of non-operation.

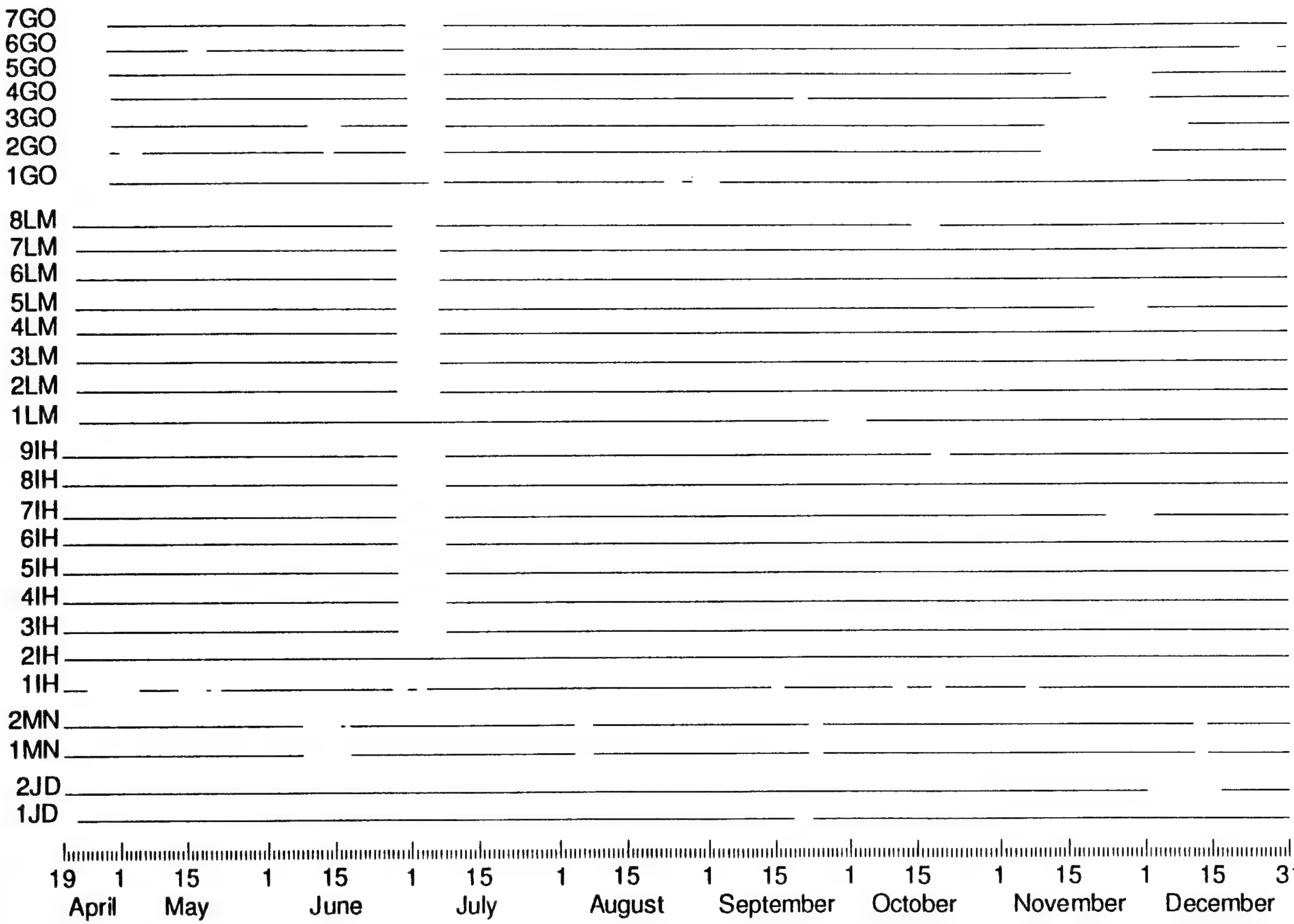


Figure 4 continued.

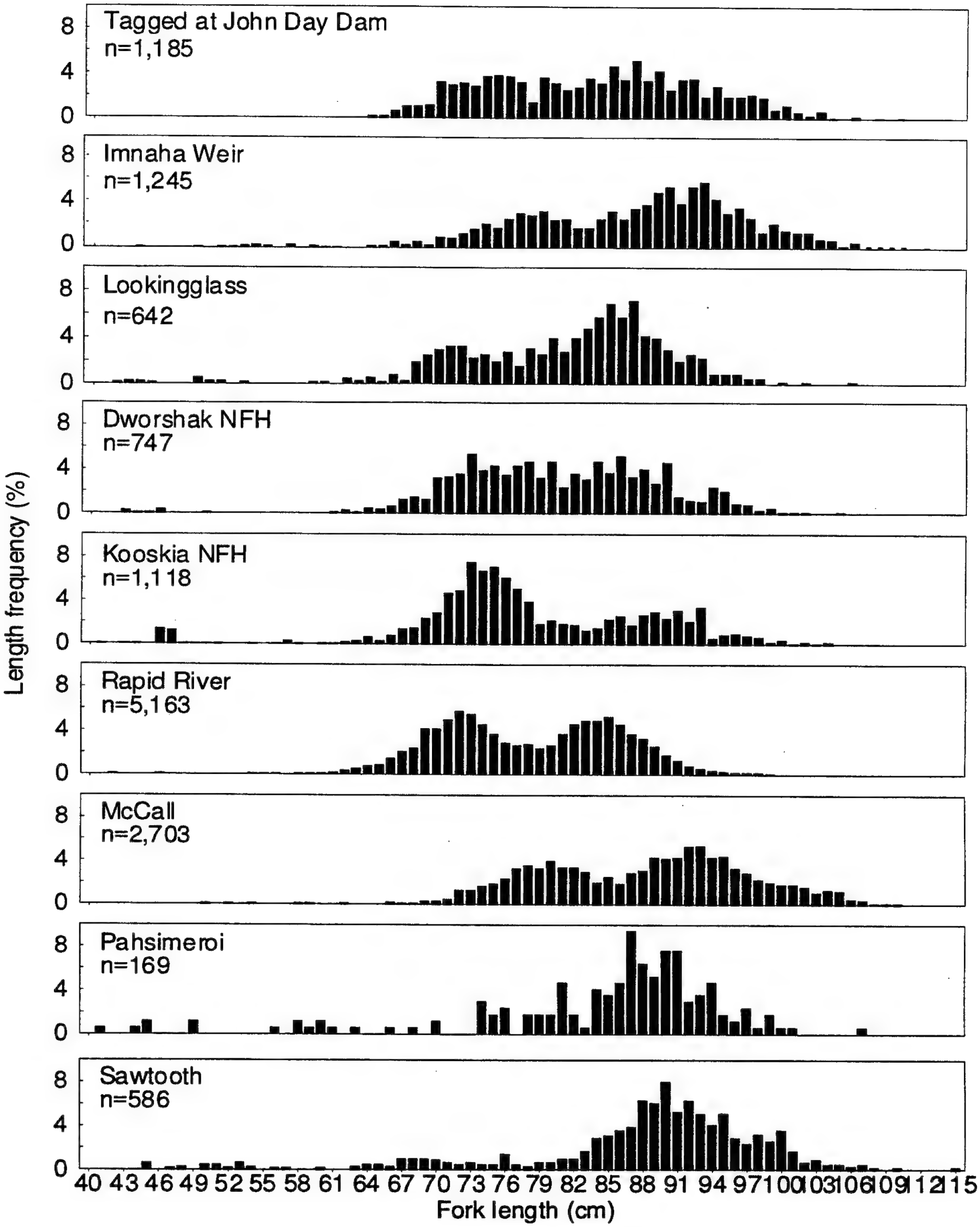


Figure 5. Length frequency distribution of spring and summer chinook salmon outfitted with transmitters at John Day Dam in 1993, and salmon returning to the various hatcheries in the Snake River basin.

The migrations of fish with transmitters and secondary V-I tags were recorded in numerous ways starting with release at John Day Dam. As fish migrated past each of the Columbia and Snake River dams and into the tributary streams, they were logged into memory by fixed-location receivers. Sitings by the mobile trackers, recaptures at the Lower Granite adult trap and at weirs and hatcheries throughout the basin, and recoveries of spawned fish in the tributary spawning areas, supplemented fixed-site receiver data. Information on some fish was provided by people operating traps at Priest Rapids Dam on the Columbia River, at Three-Mile Dam on the Umatilla River, and by people finding fish or transmitters along the river banks. Each record of a siting or recapture was added to a database and used to decipher the movements of each individual fish (Figure 6).

Results

Passage success

Of the 1,171 spring and summer chinook salmon released at John Day Dam with transmitters in 1993, 99 were last recorded downstream of John Day Dam and 24 were never heard from again after tagging. Of the 99 fish recorded downstream, the largest concentration of spring and summer chinook salmon was in the Deschutes River (Figure 7). Upstream of the tagging site, 1,048 fish are known to have passed over John Day Dam. Of these, 64 were last recorded in the John Day River and its tributaries, 9 entered the Umatilla River and its tributaries, 942 entered the tailrace area of McNary Dam, and 33 were not found. Of the 942 fish, 916 crossed McNary Dam, 362 entered the Snake River, and the remaining 554 continued up the Columbia River. Of the 554 fish going up the Columbia River, 27 were recorded in the Yakima River and its tributaries, 19 were recorded at Ringold Hatchery and 434 are known to have made it to Priest Rapids Dam. The largest concentration of fish that passed Priest Rapids Dam entered the Wenachee River and its tributaries, accounting for 93 spring and summer chinook salmon.

Of the 362 fish recorded in the Snake River, 353 were recorded as entering the tailrace at Ice Harbor Dam, 339 at Lower Monumental Dam, 335 at Little Goose Dam, and 312 at the Lower Granite Dam tailrace (Figure 7). In addition, 292 of the fish were recorded passing over Lower Granite Dam (82.7% of the fish moving up to Ice Harbor Dam after release), and 291 fish (82.4%) were last recorded upstream from Lower Granite Reservoir. After removing the 14 fish that entered the Tucannon River and 1 fish that entered Lyons Ferry Hatchery, the survival of chinook salmon with transmitters from the Ice Harbor Dam tailrace to upstream of Lower Granite Reservoir was at least 86.1% (291 / (353 - 15)).

Processing of Radio Tracking Data

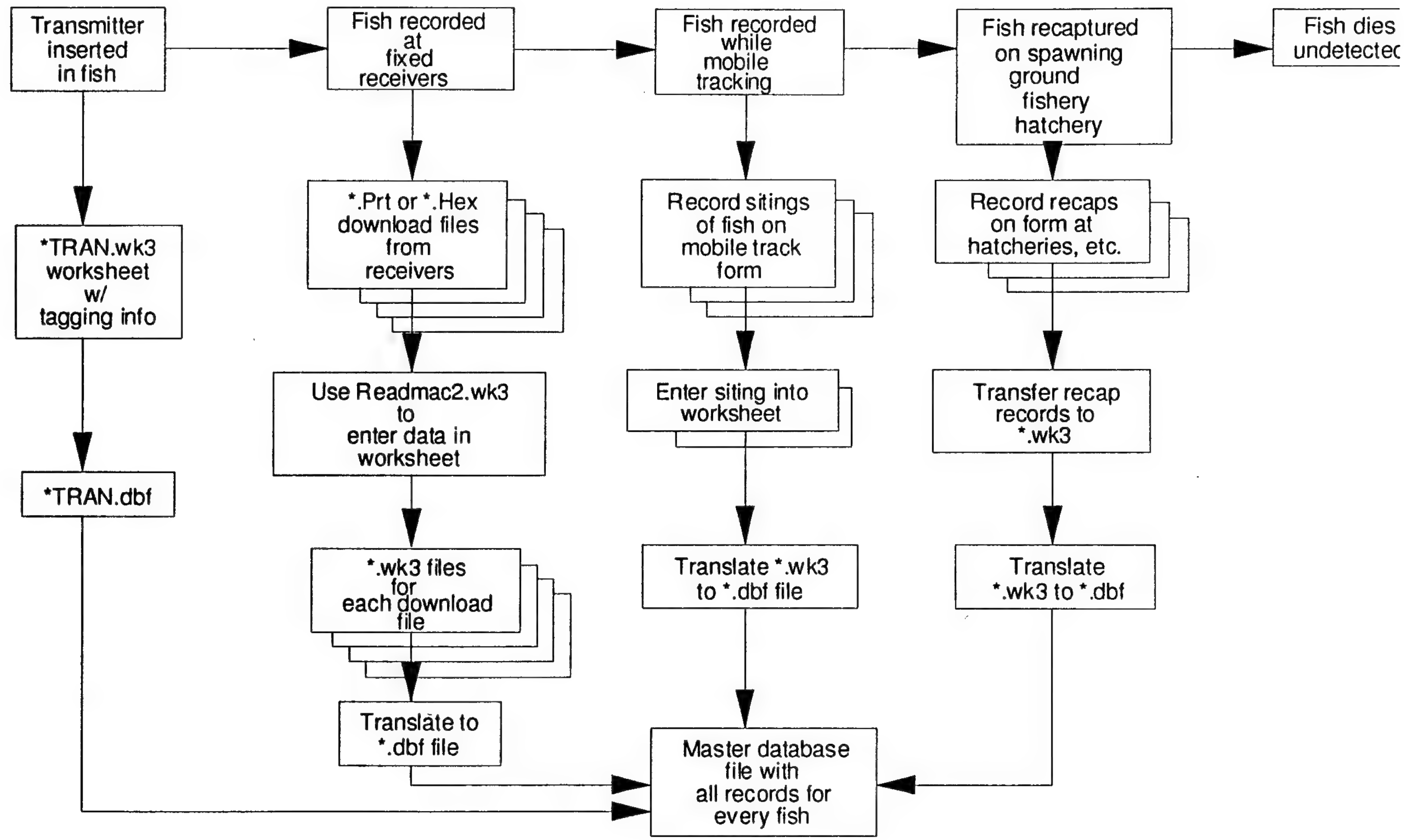


Figure 6. Diagram of steps to collect and process the different types of radio telemetry data (fixed-site receivers, mobile tracking, recaptures, etc.) for inclusion in master database files for each species.

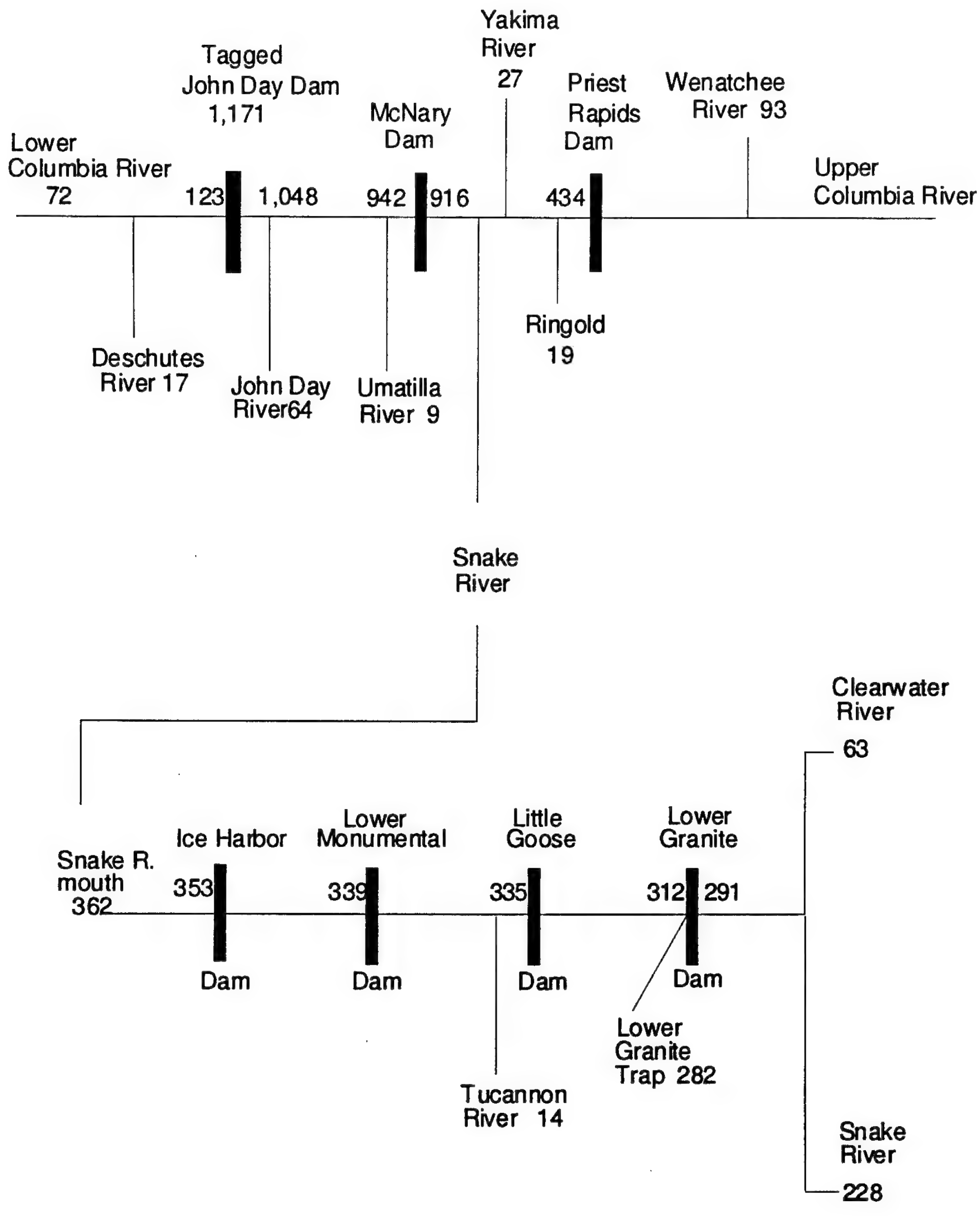


Figure 7. Map of the Columbia River from downstream of John Day Dam to upstream of Priest Rapids Dam, and of the lower Snake River showing the number of spring and summer chinook salmon released with transmitters at John Day Dam that were subsequently recorded on mobile tracking receivers or on fixed receivers in the tailraces downstream from each of the four Snake River dams or captured at the Lower Granite adult trap in 1993.

Few chinook salmon with transmitters fell back over one or more dams in 1993, even though spill occurred at the four lower Snake River dams. Nineteen salmon fell back at the dams; 9 at Lower Granite (3.1% of the 292 salmon that crossed the dam), 5 at Little Goose, 3 at Lower Monumental, and 2 at Ice Harbor dams. These numbers include three fish that fell back from Lower Granite and Little Goose dams and subsequently entered the Tucannon River, and one fish that fell back over Little Goose and Lower Monumental dams but eventually entered the Tucannon River. Of the nine Lower Granite Dam fallbacks, two successfully reascended the dam and were recaptured in hatcheries, and three fish disappeared in the Little Goose pool. The other four went downstream at least as far as the tailrace of Little Goose Dam, where three entered the Tucannon River and one was last heard in the Little Goose pool after crossing Little Goose Dam a second time. Two of the five fallbacks at Little Goose Dam reascended, then crossed over Lower Granite Dam. One of these fish entered the Lochsa River and the other the South Fork Clearwater River. One fish fell back and entered the Tucannon River, and the two remaining chinook salmon disappeared - one in the Lower Monumental Dam pool and the other near the mouth of the Snake River. Of the three fish that fell back after crossing Lower Monumental Dam, one recrossed the dam and entered the South Fork Salmon River. One of the other two, exited the Snake River to the Columbia River, and the other was last recorded in the Ice Harbor pool. Two fish crossed Ice Harbor Dam and then fell back downstream. One of these fish was found while mobile tracking in the Columbia River, and the other recrossed Ice Harbor Dam, and was last recorded in the Lower Granite Dam tailrace. Corps of Engineers personnel counted the number of spring and summer chinook salmon without transmitters that fell back through the bypass system at Lower Granite Dam in 1993 and reported 126 adults and 36 jacks during the April through August period (about 0.55 % of the 29,237 salmon counted).

Of the 353 fish detected in the Ice Harbor Dam tailrace, 340 crossed over the dam and were available to migrate upstream from Ice Harbor Dam. Of those, 339 salmon were detected in the tailrace of Lower Monumental Dam, and 335 passed the dam. Of the 320 fish known to have traveled from the forebay of Lower Monumental Dam to the tailrace below Little Goose Dam, 314 crossed Little Goose Dam. Of the 312 fish migrating from the forebay of Little Goose Dam to the tailrace of Lower Granite Dam, we recorded 292 fish as having passed over Lower Granite Dam (fish recorded at the Lower Granite trap, at the top of the ladder, or at receivers upstream from the reservoir).

NMFS personnel at the Lower Granite trap recorded 282 of 292 (96.6%) spring and summer chinook salmon known to have crossed Lower Granite Dam. Fourteen of the 312 fish migrating upstream from the forebay of Little Goose Dam were not recorded again after being recorded at the Lower Granite trap. The numbers of chinook salmon

recorded at the trap or on receivers provide minimum survival rates because the trap and the receivers located downstream from each dam or at the tops of the ladders were not 100% efficient. At the tailrace receivers downstream from the dams, a fish swimming past in the deepest part of the channel might not get recorded (range limited to water depths less than 12 m), and there were brief periods when each receiver was out of operation for service or because of a malfunction. Downstream tailrace receiver performances at Lower Granite, Little Goose, and Lower Monumental dams were 296/311 (95%), 320/319 (100%) and 297/338 (87.4%), respectively. More fish were recorded on the Little Goose Dam tailrace receiver than actually passed the dam because some fish destined for the Tucannon River were first recorded at Little Goose Dam upstream from the mouth of the Tucannon River, then these fish moved back downstream and entered the river. The tailrace receiver at the Ice Harbor Dam location was an exception, however, and was particularly troublesome in 1993. For some unknown reason, this site was extremely noisy with extraneous electronic signals. High noise levels, we believe, caused the radio frequency amplifier circuitry of the receiver to be overdriven. The SRX-400 receiver would exit the scanning program, and data was lost from that point in time until the receiver was reset. Because of the intermittent nature of the noise, we never positively determined its source (man-made or atmospheric), exactly when it occurred, whether it was broadband or frequency specific, or its relative strength. The tailrace location fixed-receiver site below Ice Harbor Dam recorded only 212 of the 362 (58.6%) radio-tagged spring and summer chinook salmon known to have entered the Snake River in 1993.

DSP/SRX receivers and single-point underwater antennas installed at the top of each fish ladder and within the fishway collection channels at the four lower Snake River dams were at least 90% effective, in spite of a receiver software problem and an operator downloading error. Both problems occurred at all the dams and caused a loss of data on all receivers. The receiver software problem was discovered in late April after installing new PROMS in all SRX-400 receivers to allow recognition of 1993 transmitter codes. The problem expressed itself as an inability of the DSP modified SRX-400 and DSP-500 receivers to communicate with each other at 19,200 baud, and essentially all DSP data from 22 - 27 April were lost until all receivers were reset to 4800 baud rate. All data from 29 June to 7 July were also lost through operator error, when all receivers were downloaded at the 19,200 baud rate, but the laptop computer being used was incapable of accurately storing and recording data above 9,600 baud, making all retrieved data unintelligible.

At Ice Harbor Dam, of 339 spring and summer chinook salmon known to have exited the top of the north and south shore fish ladders, 323 (95.3%) were recorded on DSP/SRX receivers. Top of the ladder DSP receiver efficiency at Lower Monumental Dam was 304/335 (90.8%), and efficiencies at Little Goose and Lower Granite dams were 289/312 (92.6%) and 269/291 (92.4%), respectively. DSP/SRX receivers and single-point underwater antennas within the fishways at all four lower Snake River dams

in 1993 were effective and provided a clear picture of where fish were spending their time in the fishways while passing each dam. Precise data on when and where fish had entered and approached the fishways, and where they fell out of the fishways were also obtained. DSP/SRX receiver reliability was high in 1993, with few gaps in the data resulting from equipment failures (Figure 4).

Of the 292 fish outfitted with transmitters that we know passed over Lower Granite Dam, excluding fallbacks, one was last heard when exiting the ladder, leaving 291 radio-tagged spring and summer chinook salmon available to enter either the Snake or Clearwater rivers upstream from Lower Granite Reservoir. Sixty-three of the 291 fish (21.6%) were found to have entered the Clearwater River, and 228 (78.4%) the Snake River upstream from Lower Granite Reservoir (Table 1). The 291 fish that entered either the Clearwater or Snake rivers upstream from the reservoir amounted to 86.1% of the 353 fish that had moved upstream to the tailrace of Ice Harbor Dam, adjusted to 338 by subtracting the 14 fish that entered the Tucannon River and one that entered Lyons Ferry Hatchery.

Of the 340 chinook salmon with transmitters that crossed over Ice Harbor Dam, adjusted to 325 for Tucannon River and Lyons Ferry Hatchery returns, 292 crossed over Lower Granite Dam for a minimum survival rate of 89.9%, a rate similar to that calculated from counts of adult spring and summer chinook salmon at Ice Harbor and Lower Granite dams in 1993 (28,924/31,513 = 0.918).

As in the previous two study years, fish distributions throughout the Snake River basin in 1993 were analyzed on the basis of last sitings of fish while mobile tracking, recordings at receivers, recaptures at weirs or hatcheries, and recoveries on spawning grounds or along the rivers. Of the 362 fish known to have entered the Snake River, nine were last recorded by mobile trackers near the mouth of the Snake River one or more times, but that was the last siting, and 14 others migrated at least as far as the tailrace fixed receiver site, 1.6 km downstream from Ice Harbor Dam, including one fish that passed over Ice Harbor Dam, but was never recorded again after exiting the top of the ladder (Table 1). Based on the analysis of migration records, at least 22 (6.1%) of the 362 fish entering the Snake River in 1993, either died in the Snake River downstream from Ice Harbor Dam or moved downstream into the Columbia River where they died or migrated into other streams undetected. In 1992, 70 (12.3%) of the salmon released at Hood Park near the mouth of the Snake River did not cross over Ice Harbor Dam.

The Lower Granite Dam tailrace and reservoir were the last places that 21 of the fish were located (Table 1). A few of those fish may have moved up beyond the Lower Granite pool, but were undetected by fixed-location receivers or mobile trackers. Fish that regurgitated transmitters in the Lower Granite pool, but were recaptured at hatcheries or fish weirs were identified if they still had the VI tag, and it was noted, and have been included in Table 1. Those that migrated into tributaries where they were

Table 1. Recapture location or last siting of spring and summer chinook salmon outfitted with transmitters and released at John Day Dam in 1993. Last sitings were at fixed-location receivers or by mobile trackers. Recaptures were at hatcheries, fish weirs, during spawning ground surveys, and by people who found fish along the rivers.

Location-description	Number of fish	Percent of fish entering Snake R.	Percent of fish tagged
John Day Dam release site	24		2.1
Columbia River			
Downstream of John Day Dam	71		6.1
Sandy River	1		0.1
White Salmon River	1		0.1
Hood River	3		0.3
Deschutes River			
Mouth to Sherars Falls	10		0.9
Sherars Falls trap	1		0.1
Pelton Dam trap	9		0.8
Klickitat River	3		0.3
Subtotal	123		10.5
John Day Dam ladders	22		1.9
Upstream of John Day Dam	11		0.9
John Day River	18		1.5
No. Fk. John Day River	19		1.6
Granite Creek	9		0.8
Clear Creek	7		0.6
Middle Fk. John Day River	10		0.9
Clear Creek	1		0.1
Umatilla River	6		0.5
Meacham Creek	3		0.3
Subtotal	106		9.1
McNary Dam ladders	21		1.8
Upstream of McNary Dam	5		0.4
Upstream from the Snake River	554		47.3
Subtotal	580		49.5

Table 1. continued.

Location-description	Number of fish	Percent of fish entering Snake R.	Percent of fish tagged
Lower Snake River			
Downstream from Ice Harbor Dam	9	2.5	0.8
Ice Harbor Dam and pool	14	3.9	1.2
Lower Monumental Dam and pool	4	1.1	0.3
Lyon's Ferry Hatchery	1	0.3	0.1
Tucannon River			
Tucannon trap	1	0.3	0. 1
Downstream from trap	8	2.2	0.7
Upstream from trap	5	1.4	0.4
Little Goose Dam and pool	8	2.2	0.7
Lower Granite Dam and pool	21	5.8	1.8
Subtotal	71	19.6	6.1
Clearwater River drainage			
Clearwater River			
Receiver site	3	0.8	0.3
Mouth to No. Fk. Clearwater R.	2	0.6	0.2
North Fork to Selway River	2	0.6	0.2
Lolo Creek	2	0.6	0.2
Kooskia National Fish Hatchery	13	3.6	1.1
Clear Creek	2	0.6	0.2
North Fork Clearwater River	1	0.3	0.1
Dworshak National Fish Hatchery	5	1.4	0.4
South Fork Clearwater River	4	1.1	0.3
Newsome Creek	1	0.3	0.1
Crooked River	3	0.8	0.3
Red River	2	0.6	0.2
American River	1	0.3	0.1
Selway River	7	1.9	0.6
Lochsa River	4	1.1	0.3
Brushy Fork Creek	1	0.3	0.1
Crooked Fork Creek	3	0.8	0.3
Powell weir	6	1.7	0.5
White Sands Creek	1	0.3	0.1
Subtotal	63	17.4	5.4

Table 1. continued.

Location-description	Number of fish	Percent of fish entering Snake R.	Percent of fish tagged
Snake River drainages upstream from Lewiston			
Snake River			
Lewiston to Hells Canyon Dam	8	2.2	0.7
Hells Canyon Dam	4	1.1	0.3
Grande Ronde River drainage			
Grande Ronde River	8	2.2	0.7
Lookingglass Creek	4	1.1	0.3
Lookingglass Fish Hatchery	7	1.9	0.6
Catherine Creek	1	0.3	0.1
Wenaha River	4	1.1	0.3
Wallowa River	3	0.8	0.3
Bear Creek	1	0.3	0.1
Minam River	4	1.1	0.3
Lostine River	2	0.6	0.2
Subtotal	46	12.7	3.9
Imnaha River drainage			
Imnaha River			
Imnaha River weir	8	2.2	0.7
Downstream from weir	2	0.6	0.2
Upstream from weir	15	4.2	1.3
Subtotal	25	6.9	2.1
Salmon River drainage			
Lower Salmon River			
Mouth to Riggins	1	0.3	0.1
Receiver site	3	0.8	0.3
Little Salmon River	7	1.9	0.6
Rapid River upstream from weir	2	0.6	0.2
Rapid River downstream from weir	1	0.3	0.1
Rapid River Fish Hatchery	23	6.4	2.0
Middle Salmon River area			
Riggins to North Fork	2	0.6	0.2

Table 1. continued.

Location-description	Number of fish	Percent of fish entering Snake R.	Percent of fish tagged
South Fork Salmon River	56	15.5	4.8
South Fork Salmon weir	15	4.1	1.3
Secesh River	2	0.6	0.2
Lake Creek	1	0.3	0.1
East Fork of South Fork			
Johnson Creek	5	1.4	0.4
Middle Fork Salmon River			
Receiver site	7	1.9	0.6
Big Creek	1	0.3	0.1
Camas Creek	2	0.6	0.2
Loon Creek	1	0.3	0.1
Sulphur Creek	1	0.3	0.1
Bear Valley Creek	4	1.1	0.3
Elk Creek	1	0.3	0.1
Marsh Creek	3	0.8	0.3
Beaver Creek	1	0.3	0.1
Capehorn Creek	1	0.3	0.1
Subtotal	140	38.7	12.0
Salmon River upstream from North Fork	4	1.1	0.3
Lemhi River	1	0.3	0.1
Hayden Creek	1	0.3	0.1
Pahsimeroi Fish Hatchery	1	0.3	0.1
East Fork Salmon River	3	0.8	0.3
Valley Creek	2	0.6	0.2
Sawtooth Fish Hatchery weir	1	0.3	0.1
Salmon River above weir	4	1.1	0.3
Subtotal	17	4.7	1.5
Grand total	1,171	100.0	100.1

unlikely to be found by spawning ground survey crews would not have been detected. The 56 fish (71 minus the 15 fish entering the Tucannon River and Lyons Ferry Hatchery) that were last recorded between the mouth of the Snake River and the upper

end of Lower Granite Reservoir amounted to 15.5% of the 362 fish entering the Snake River. With the 14 fish that entered the Tucannon River and one Lyons Ferry Hatchery fish removed from the total migrants, the percentage becomes 16.1 (56/347) and could be considered a maximum estimate of fish that did not survive the migration between the mouth of the river and the upper end of Lower Granite Reservoir. This estimate is a maximum estimate because a few fish may not have been detected in rivers and streams upstream from the Lower Granite pool, or they may have left the Snake River undetected. Trapping and tagging of the fish may have increased the loss rate, however, the similarity of passage rates from the top of Ice Harbor to the top of Lower Granite dams based on tagged fish in this study 292/325 (89.9%), versus regular counts at the dams (92%) is evidence that tagging effects were small. The fraction of the "loss" that can be ascribed to the dams versus natural causes is unknown.

Upstream from the reservoirs, salmon enter the Clearwater River or continue up the Snake River. In 1993, the Clearwater River and its tributaries were the last locations for 63 (5.4%) of the fish released at John Day Dam (Table 1) or 63/362 (17.4%) of the radio-tagged spring and summer chinook salmon entering the mouth of the Snake River. The Snake River and its tributaries upstream from Lewiston were the last locations for 19.5% of the fish released at John Day Dam or 228/362 (63%) of the radio-tagged fish entering the Snake River. Thirteen fish entered Kooskia National Fish Hatchery, 5 fish entered Dworshak National Fish Hatchery, and 38 entered the other major tributaries (Lolo Creek, South Fork, Selway, and Lochsa rivers). The 7 remaining fish were last located throughout the Clearwater River from the mouth up to the Selway River. Three of the seven fish were last recorded at the fixed-location receiver near the mouth of the Clearwater River, two were between the mouth of the Clearwater River and the North Fork Clearwater River, and two were located in the stretch between the North Fork Clearwater and Selway rivers.

The Grande Ronde basin was the last location of 46 (12.7%) of the fish entering the Snake River with transmitters (Table 1). Eight fish were last seen in the Grande Ronde River, seven entered Lookingglass Fish Hatchery, four remained in Lookingglass Creek and the remainder were located in other tributaries, mainly the Minam, Wallowa and Wenaha rivers.

The Imnaha River was the last location for 25 (6.9% of those entering the Snake River) chinook salmon released with transmitters in 1993 that entered the Snake River (Table 1). All 25 fish recorded at the Imnaha River receiver located near Fence Creek, 23 km upstream from the mouth, were later located upstream. Fifteen fish were last recorded in the Imnaha River upstream from the weir, and 8 fish were recaptured at the weir. There was no concentration of radio-tagged fish downstream from the weir, as was observed in 1992.

The Salmon River was the apparent destination of the largest proportion of the chinook salmon released with transmitters; 157 of the fish (43.4% of those entering the Snake River) were last located in that drainage (Table 1). One fish was last recorded in the lower Salmon River from the mouth upstream 138.7 km to Riggins, and probably died before spawning because the lower Salmon River is not known as a spring or summer chinook spawning area. The Little Salmon River was the last location for 7 fish (1.9%). Twenty-six fish (7.2%) entered Rapid River, a tributary of the Little Salmon River; 1 was last located in the river (0 - 1.6 km) downstream from the trap, 23 were caught at the trap and taken to Rapid River Fish Hatchery, and 2 fish were last located upstream from the trap. Although most of the 33 fish (9.1%) with transmitters found in the Little Salmon and Rapid Rivers were probably destined for the hatchery, a few probably spawned in the streams. Only two fish were last recorded in the Salmon River between Riggins and North Fork, and those may have been fish that died before spawning.

The South Fork, the next major drainage up the Salmon River from Riggins, was the last location for 79 spring and summer chinook salmon (21.9% of those entering the Snake River) (Table 1). Fifty-six were found in the main stem South Fork between the receiver site and the fish weir near Knox Bridge, five were found in Johnson Creek, two in the Secesh River and one in Lake Creek. Fifteen fish were recaptured at the South Fork Salmon weir. There was no way to estimate mortality within the South Fork.

In the Middle Fork drainage, 15 fish were found in several tributaries and 7 fish were last recorded at the receiver at the mouth of the Middle Fork (Table 1). Because much of the drainage is unroaded, our coverage was less complete than in other basins. Some of the seven fish may have died before spawning, but we do not know the number.

Of the 17 fish (4.7%) last recorded in the upper Salmon River basin upstream from North Fork, 4 were last recorded in the Salmon River, 1 was found in the Lemhi River, 1 in Hayden Creek, 1 in Pahsimeroi Hatchery, 3 were located in the East Fork Salmon River, 2 in Valley Creek, and 5 were trapped at the Sawtooth Fish Hatchery weir (Table 1).

In summary, of the fish released with transmitters that entered the Snake River in 1993 (362 fish), 2.5% (9 fish) were last recorded near the mouth and either left the river after entering, regurgitated their transmitters, or died. We assume some of these fish were not destined for Snake River tributaries. An additional 12.9% did not get upstream beyond the Lower Granite pool. Of the 362 fish entering the Snake River, 4.2% were recorded in the Tucannon River and Lyons Ferry Hatchery, the Clearwater River drainage had 17.4% of the last-record fish, 3.3% were last recorded in the Snake River upstream from Lewiston, 9.4% were recorded in the Grande Ronde basin, 6.9% entered the Imnaha River, and 43.4% ended up in the Salmon River (Table 1). If we assume fish last recorded in the lower Snake River between the Ice Harbor Dam tailrace and the upper end of Lower Granite Reservoir (47 fish, Table 1) were destined for the tributaries

in the same proportions as the survivors, then the distribution by Snake River tributary becomes 4.8% in the Tucannon River, 20.7% destined for the Clearwater River, 4.0% destined for the Snake River upstream from Lewiston, 11.1% destined for the Grande Ronde River, 8.2% destined for the Imnaha River, and 51.3% destined for the Salmon River.

An estimate of the number of fish with radio transmitters that died before spawning can be made on the basis of the last place the fish were located. Such estimates contain both negative and positive biases, because fish last located in a section of river where spawning has not been seen (usually main stems of the major tributaries) were counted as fish that died prematurely, and fish located in a spawning stream would be counted as a fish that spawned. In the first case, the fish may have spawned where located or in a tributary upstream, but was not detected. In the second case, not all fish that make it to a stream used for spawning survive and spawn.

Of the 353 chinook salmon with transmitters that we believe tried to migrate up the Snake River past Ice Harbor after being released at John Day Dam, 56 (15.9%) were not located upstream from the four lower Snake River dams and reservoirs or in the Tucannon River or Lyons Ferry Hatchery (Table 1), and can probably be classed as fish that died prematurely, although a few may have passed upstream undetected. In the Clearwater River drainage, 7 of the 63 fish found in that basin were last seen in the main stem Clearwater River between the mouth and the Selway River. Two fish were last heard in Clear Creek (one of which died, and one was passed upstream of Kooskia NFH) and another fish was last heard in the North Fork Clearwater River. Spring and summer chinook salmon have not been seen spawning routinely in the main stem of the Clearwater River so nine of those fish may have died before spawning or entering the two hatcheries in that section of stream. If they were losses, they would increase the loss rate to 18.4% (65/353). The eight fish last recorded in the Snake River between Lewiston and Hells Canyon Dam, another stretch with no history of spawning for these fish, would increase the loss to 20.7%. We know of no fish that died before spawning in the Imnaha River and could not class any of the fish entering the Grande Ronde River as losses, although some probably occurred. In the Salmon River, 4 fish were last located downstream from Riggins, and 2 were last found between Riggins and North Fork, both stretches of river with no history of spawning. Seventeen fish were last located in the Salmon River upstream from North Fork and its tributaries and could have spawned; no fish were found dead and unspawned in that section of river in 1993. Some of the fish that entered the South and Middle Forks of the Salmon River may also have been losses, but we had no way of estimating the number.

With the likely losses in the Salmon River drainage, the minimum estimated prespawning loss rate of fish with radio transmitters in 1993 between Ice Harbor Dam and the tributaries or hatcheries was 22.4%, a smaller number than the estimates in 1991 (46%) and 1992 (37.4%) and lower than the average loss calculated in a different

way for prior years. Bjornn (1990) estimated that prespawning losses for wild spring and summer chinook salmon in the Snake River basin averaged 45% for the 1962-1968 period (only Ice Harbor Dam present), and 54% for the 1975-1988 period (all four dams in place). He estimated the number of wild spawners passing Ice Harbor Dam and compared that number with the number of spawners represented by the redds counted in the Snake River basin.

Spring and summer chinook salmon distribution

A comparison of the fish found in each drainage versus the time they were tagged and released at John Day Dam provides an estimate of the distribution of spring versus summer chinook salmon throughout the Snake River basin. As pointed out previously, 746 (63.7%) of the fish released at John Day Dam with transmitters were released in April through 5 June (the traditional cutoff date for spring and summer chinook salmon at John Day Dam), and 425 (36.3%) were released from 6 June through 29 July. Using the 5 June cutoff date, we have assumed that most of the fish released in April, May, and through 5 June were spring chinook salmon, and those from 6 June until 29 July were summer chinook salmon. Of the 291 records of fish known to have crossed Lower Granite Dam, 203 (69.8%) of the fish had been released from April - 5 June and 88 (30.2%) had been released from 6 June through 29 July (Figure 8), little change from the percentages at release, which is what we would expect unless there was a differential mortality for spring versus summer chinook salmon or the proportions of spring and summer chinook salmon entering the Snake River are quite different from those continuing up the mid Columbia River.

Upstream from Lower Granite Dam, the distribution of spring and summer chinook salmon varied by tributary. Of the 66 fish with transmitters entering the Clearwater River in 1993, 65 were spring chinook salmon based on the 5 June cutoff date, and 1 was a summer chinook salmon (Figure 8). Three of the 66 fish which were recorded on the Clearwater River receiver, later entered the Snake River. Of the 233 salmon with transmitters heading up the Snake River and into tributaries upstream from Lewiston/Clarkston, 145 (62.2%) were from the spring run and 88 (37.8%) were fish of the summer run. Five of the 233 fish recorded on the Snake River receiver were subsequently last heard downstream of the receiver site or in other drainages.

Within the Clearwater River basin, virtually all of the fish recorded in the Clearwater, Selway, and South Fork rivers and tributaries were spring chinook salmon in 1993 (Figure 9). One summer chinook salmon was last heard at the lower Clearwater River receiver site.

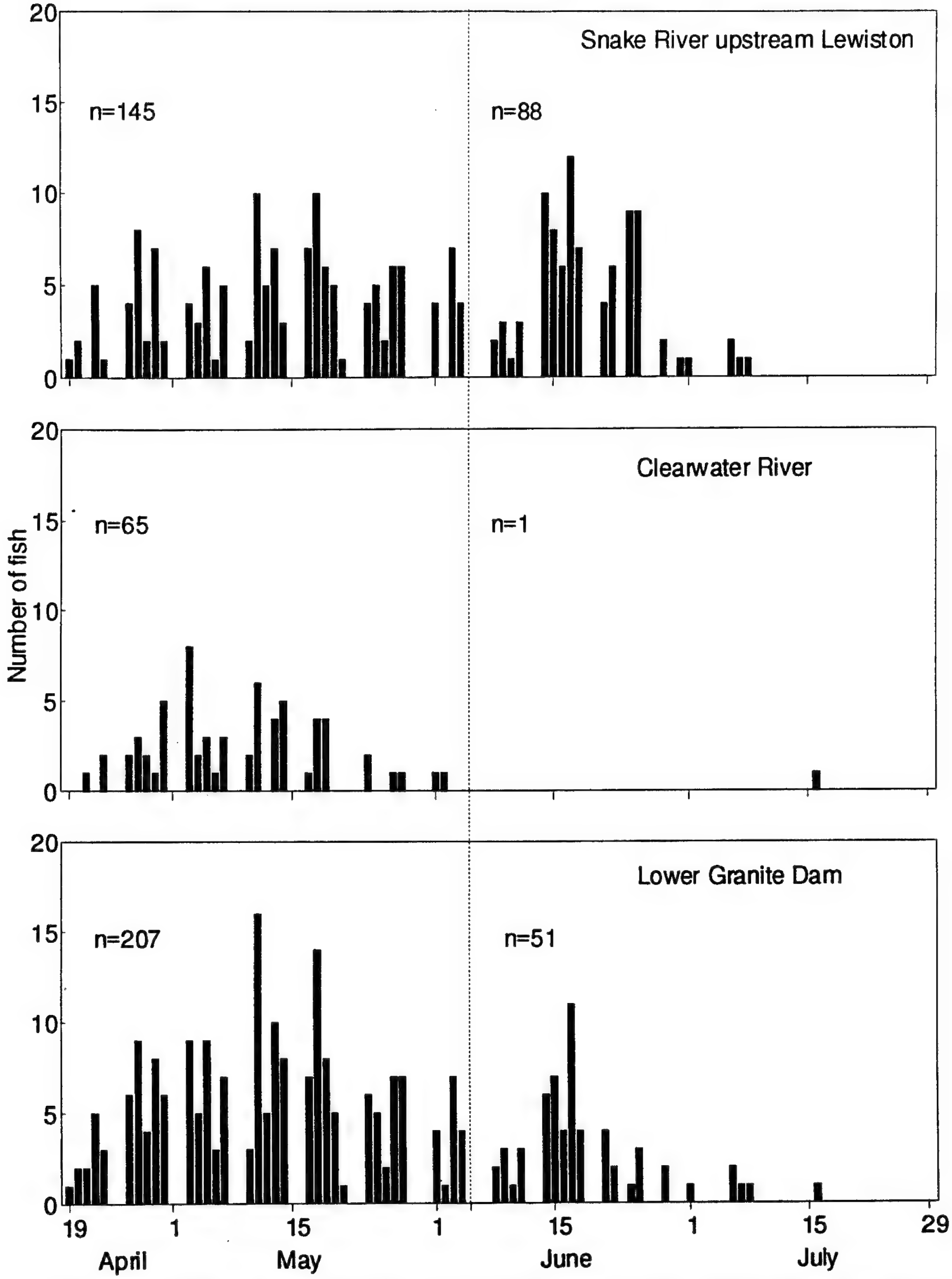


Figure 8. Frequency distribution of chinook salmon with transmitters passing Lower Granite Dam and entering the Clearwater and Snake River upstream from Lewiston, based on time of tagging and release at John Day Dam in 1993.

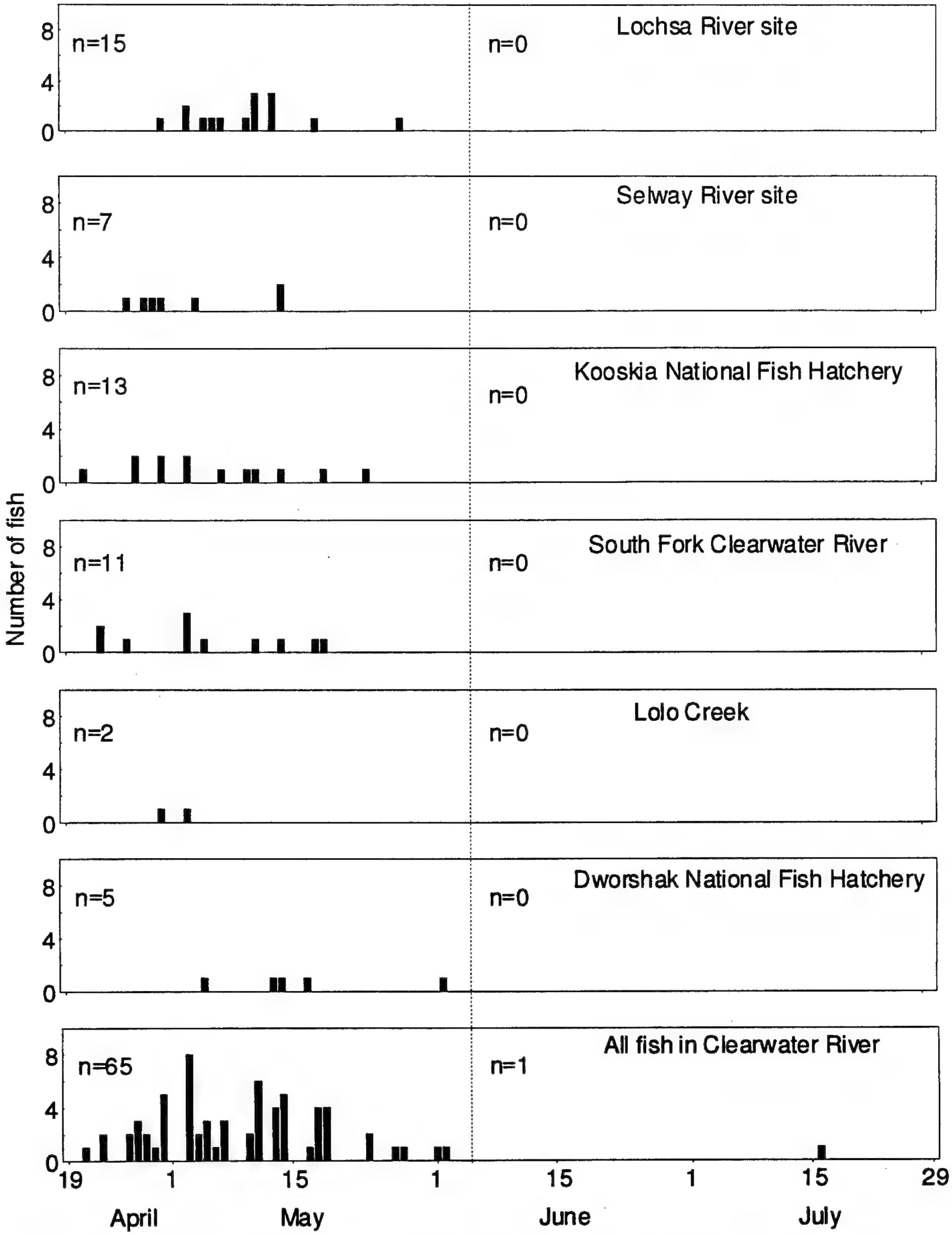


Figure 9. Frequency distribution of chinook salmon with transmitters entering the Clearwater River and tributaries and hatcheries within the basin, based on time of tagging and release at John Day Dam in 1993.

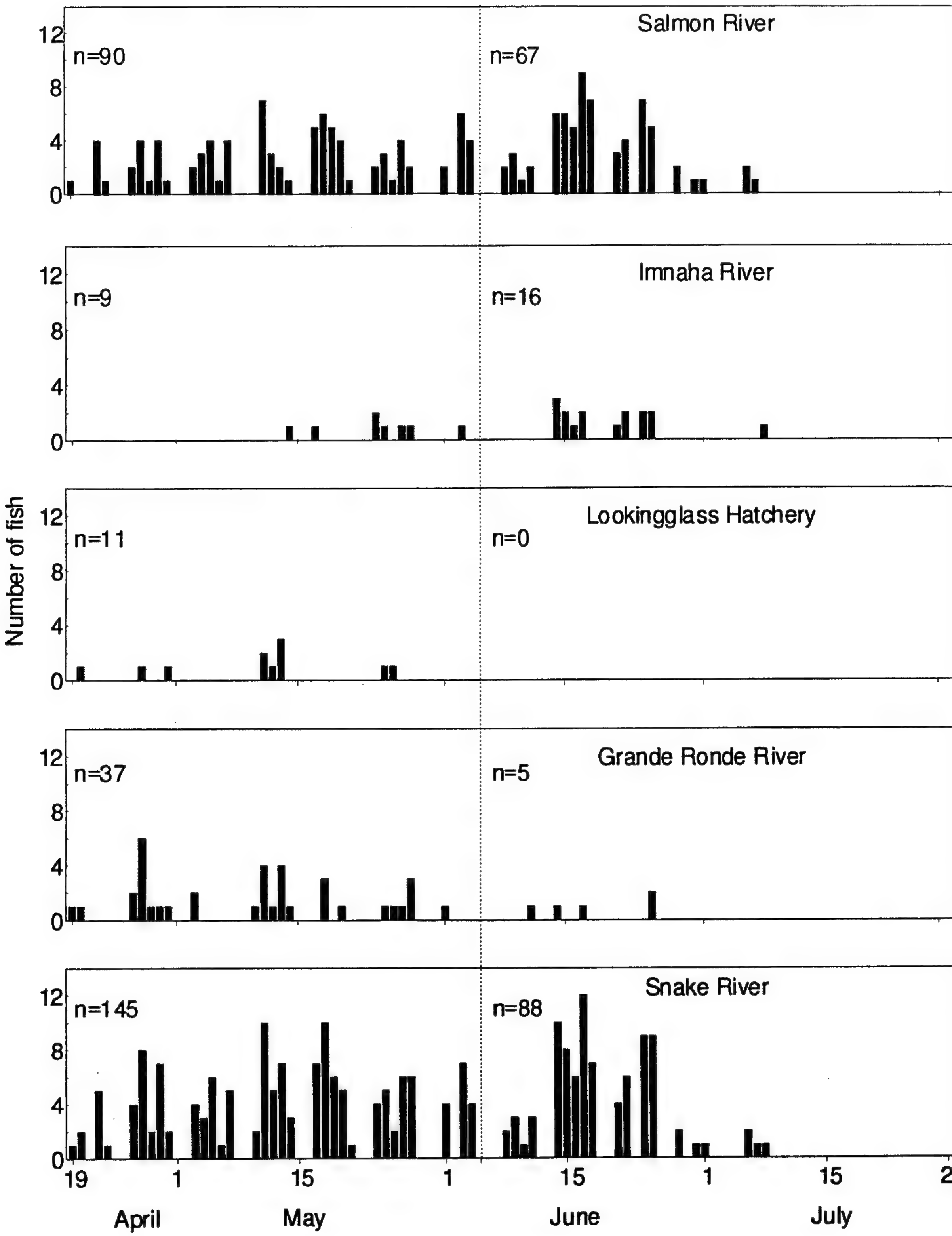


Figure 10. Frequency distribution of chinook salmon with transmitters entering the Snake River, tributaries, and hatcheries between Lewiston and the mouth of the Imnaha River, based on time of tagging and release at John Day Dam in 1993.

In the Grande Ronde and Imnaha river basins, both spring and summer chinook salmon entered the rivers (Figure 10). All but about 5 of the 42 salmon recorded as entering the Grande Ronde River were spring chinook and the remainder were classified as summer chinook salmon. Only 9 of 25 chinook salmon entering the Imnaha River were classified as spring chinook salmon, and the remaining 16 were part of the summer run. Eleven spring chinook salmon were recaptured at Lookingglass Fish Hatchery or last recorded in Lookingglass Creek in 1993. Fish returning to the Wenaha, Wallowa, Minam and Lostine rivers, and Bear and Catherine creeks, consisted of 15 spring and 1 summer chinook salmon, and are included in the Grande Ronde River fish (Figure 10).

Of the 157 salmon with transmitters entering the Salmon River in 1993, 57.3% were spring chinook salmon and the remaining 42.7% were summer-run fish (Figure 11). Within the tributaries of the drainage, the proportion of spring- or summer-run fish varied widely. All 33 fish recorded in the Little Salmon River and its tributaries, including Rapid River Hatchery recaptures, were spring chinook salmon in 1993. In other streams, the proportions of fish that might have been summer chinook salmon were larger.

In 1993, a total of 79 chinook salmon with transmitters were recorded in the South Fork of the Salmon River drainage. Based on the time they were tagged at John Day Dam, 24 (30.4%) of the fish would be classed as belonging to the spring run (Figure 11). Johnson Creek had 2 spring and 3 summer chinook salmon. The two fish with transmitters in the Secesh River and one in Lake Creek (Table 1) would be classed as spring chinook salmon. Ten of the remaining 56 fish recorded or recaptured in the South Fork downstream from the weir near Knox Bridge, along with 9 of 15 fish recaptured at the weir, would have been classed as spring chinook salmon. We believe most, if not all, of the fish that returned to the South Fork drainage in 1993 were summer chinook salmon.

Only two of the 22 salmon with transmitters that we believe entered the Middle Fork of the Salmon River drainage were classed as summer chinook salmon in 1993 (Figure 11).

Of the 17 fish last located in the Salmon River or its tributaries upstream from the receiver at North Fork in 1993, 12 would be classed as spring chinook salmon (Figure 11). Fish were recorded or recaptured in the main Salmon, Lemhi, and East Fork of the Salmon rivers, Valley and Hayden Creeks, and salmon returned to the Pahsimeroi and Sawtooth Fish Hatchery weirs.

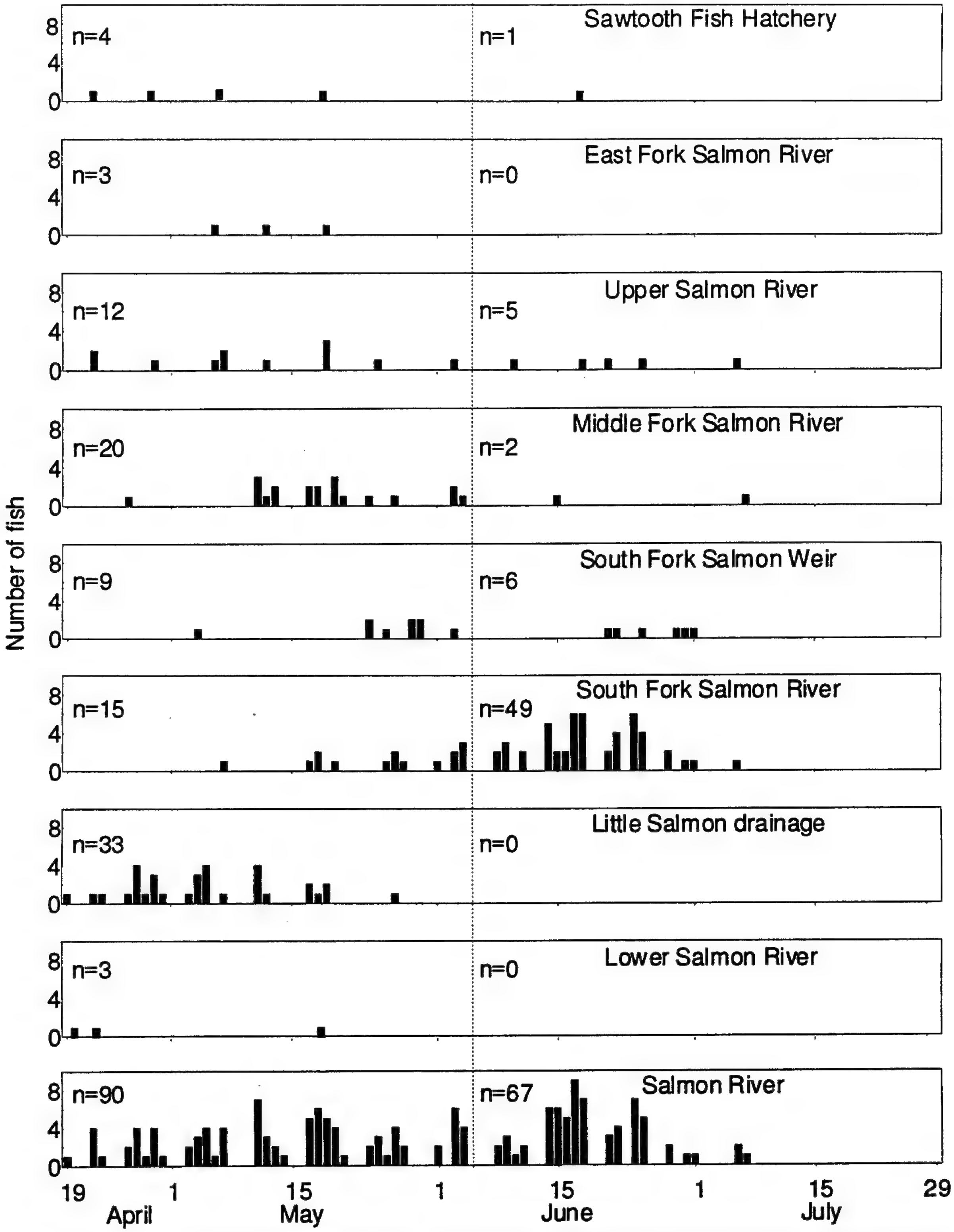


Figure 11. Frequency distribution of chinook salmon with transmitters entering the Salmon River, tributaries, and hatcheries, based on time of tagging and release at John Day Dam in 1993.

Transmitter status

Regurgitation of transmitters was monitored only during the time it took for tagged spring and summer chinook salmon to recover and exit freely from the recovery pen located in the bottom of the south ladder at John Day Dam. Twelve transmitters (1.0%) were disgorged while fish were in the recovery tank, about the same rate as 1992 at the Hood Park release site. Transmitters were recovered, tagging records changed, and the regurgitated transmitters subsequently put in other fish. Twenty-two of 282 chinook salmon checked at the Lower Granite adult trap (7.8%) had disgorged their transmitters after release at John Day Dam. The regurgitation rate after release was higher than in 1991 or 1992. The last check on regurgitation rate was for the fish recaptured at weirs and hatcheries. Fifty-one chinook salmon (4.4%) of the 1,171 implanted with radio transmitters, which were recovered at hatcheries or from spawning grounds, with unquestioned data on transmitter status, did not have transmitters when they should have. Of these, 14 of 362 (3.9%) which entered the Snake River were recaptured without transmitters; 7 of these 14 regurgitated their transmitters sometime after being checked and verified as having a working transmitter at the Lower Granite adult trap. Fish that regurgitated their transmitters after release were partially accounted for if they had the secondary tag used in 1993 (V-I tag) in place and they were noted when they were recaptured at the Lower Granite adult trap, hatcheries, weirs in streams, and spawning grounds. A fish that regurgitated a transmitter in a non-traditional spawning area and then proceeded upstream to spawn undetected, would be counted as a loss, if the signal from the regurgitated transmitter was picked up while mobile tracking. Such fish, if properly accounted for, would not reduce the 22.4% minimum loss rate observed in 1993 from Ice Harbor Dam to the spawning grounds by more than 3-5%, in our opinion.

Lower Granite trap efficiency was high in 1993. NMFS personnel operating the trap recaptured 282 of 291 (96.9%) radio-tagged spring and summer chinook salmon known to have passed Lower Granite Dam. Radio transmitter reliability was perfect; none of the fish recaptured at the Lower Granite trap had non-working transmitters, although two transmitters were mistakenly pulled or fell out during the trapping, netting, and fish inspection process.

Migration rates

In 1993, the median number of days for spring and summer chinook salmon to pass over John Day Dam after being released in the south ladder was 0.2 d for fish ascending the south ladder, and 0.8 d for the 113 fish that exited the south ladder and passed over the dam via the north ladder (Table 2). The median number of days for 888 spring and summer chinook salmon to migrate from the release site at John Day Dam and pass

over McNary Dam was 3.5 d. After crossing McNary Dam, 27 of the 554 spring and summer chinook salmon with transmitters that migrated up the Columbia River past the Snake River entered the Yakima River. Migration time from release at John Day Dam for the 27 fish recorded in the Yakima River 29 km upstream from the mouth was 12.3 d (18.0 km/d).

Table 2. Mean and median number of days for radio-tagged spring and summer chinook salmon to migrate from the John Day Dam release site to the tops of the ladders of John Day and McNary dams in the Columbia River, and the days to pass each of the four dams in the lower Snake River in 1993.

	Number of fish	Mean number of days	Range of days	Confidence intervals (95%)	Median number of days
John Day Dam release site to:					
Top of north ladder	113	5.2	0.3-33.3	0.0-14.8	0.8
Top of south ladder	905	1.4	0.0-33.1	0.0- 7.9	0.2
Top of McNary Dam	888	5.3	1.2-42.9	0.0-14.3	3.5
Past a Snake River dam					
Ice Harbor	162	1.2	0.0-14.2	0.0-4.3	0.8
Lower Monumental	269	1.2	0.1-12.5	0.0-4.5	0.7
Little Goose	288	1.3	0.0-24.0	0.0-6.0	0.6
Lower Granite	258	1.8	0.0-17.7	0.0-6.4	1.2

The median time spring and summer chinook salmon took to pass the four lower Snake River dams in 1993 varied from a high of 1.2 d (1.8 mean d) at Lower Granite Dam to a low of 0.6 d (1.3 mean) at Little Goose Dam (Table 2). Time required for a fish to "pass" a dam was measured as the lapsed time from the last record of a fish at the tailrace receivers to the last record from the same fish on a receiver/antenna at the top of the ladders. The distribution of passage times was more spread out at Lower Granite dam compared to the other three dams (Figure 12), and reflected the fact that many fish took several days to enter the fishway and pass over the dam. Only one (0.6%) of the fish passing Ice Harbor Dam took more than 10 d to pass the dam, 5 (1.9%) of 258 chinook salmon passing Lower Granite Dam took 10 days or more, 2 of 269 (1.1%) fish

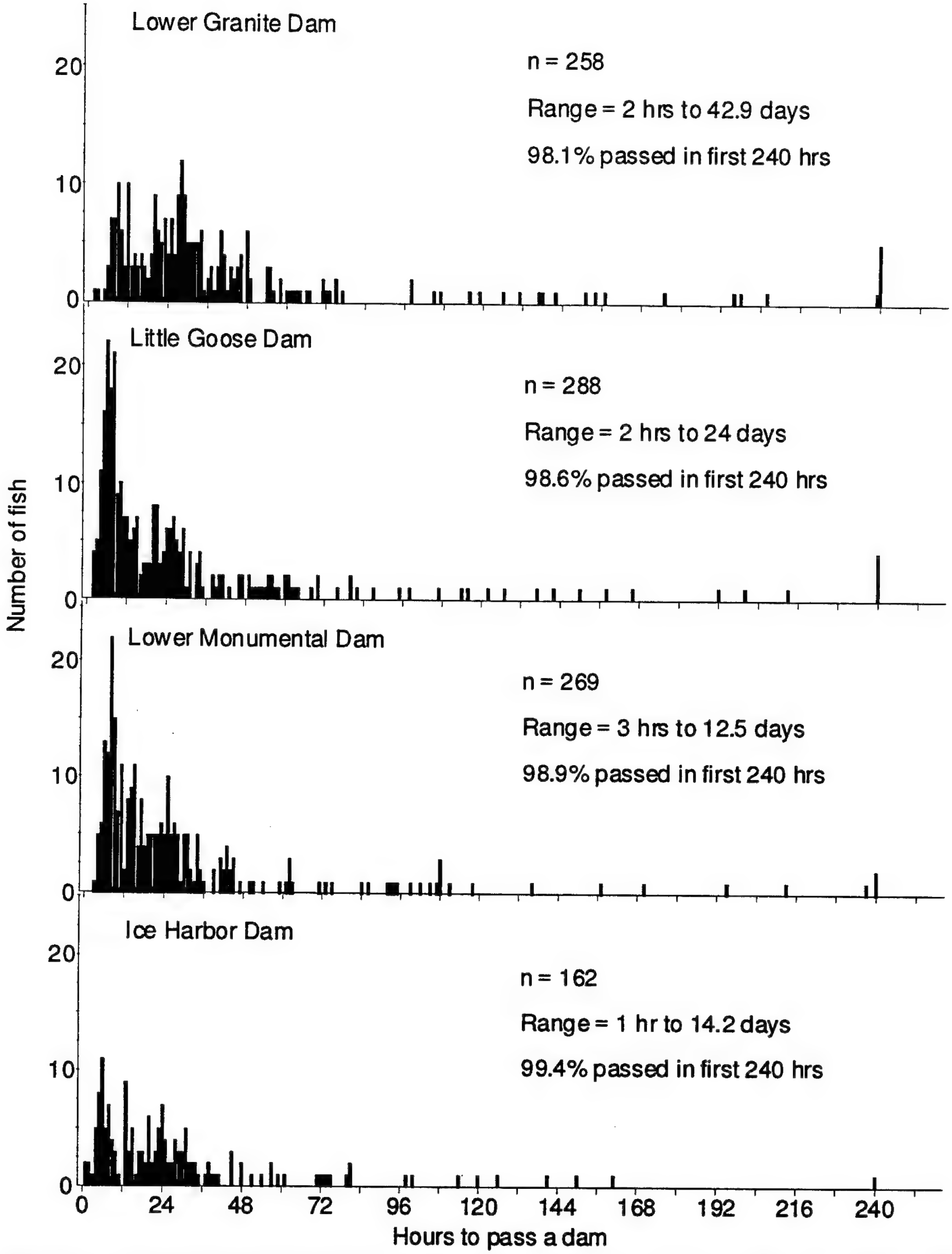


Figure 12. Frequency distribution of time to pass the four dams in the lower Snake River from the tailrace to the top of the ladder by spring and summer chinook salmon with radio transmitters in 1993.

passing Lower Monumental Dam in 1993 took longer than 10 days, and 4 of 284 fish (1.4%) passing Little Goose Dam took over 10 days. Fish may have taken longer to pass Lower Granite dam because of the trap operated in the south ladder.

Installation of DSP/SRX receivers and single-point underwater antennas within the fishways at all four lower Snake River dams in 1993 gave us a clear picture of where salmon were spending their time while passing each dam. Although our setup in 1992 gave us more complete records of fish movements at the dams than in 1991, the use of DSP/SRX receivers purchased and installed in the spring of 1993 at all dams provided the most comprehensive and accurate movement information to date.

Spring and summer chinook salmon migrations through the Snake River reservoirs in 1993 were less variable than in 1991 and 1992 (Table 3), even though 1991 and 1992 were relatively low, clear runoff flow years and spill occurred in 1993. Fish migrated from the Ice Harbor Dam forebay to the Lower Monumental Dam tailrace in 1.0 d on average (49.9 km/d), through the Lower Monumental pool in 0.9 d (50.3 km/d), through the Little Goose pool in 1.0 d (59.5 km/d), and through the Lower Granite pool to the lower Clearwater River and Snake River receiver sites in 3.0 and 1.5 d (19.6 and 42.2 km/d), respectively. In 1991, migration rates through the reservoirs, based on mean days to pass, were all higher than 47.5 km/d. The median number of days that chinook salmon took to pass through the reservoirs in 1993 were smaller than the mean days (Table 3), an indication of distributions skewed to the right (Figure 13). Passage rates (km/d) based on median days were slightly higher than those based on mean days, and faster than rates observed in 1991 or 1992.

The average rates of passage of salmon with transmitters in 1993 from John Day Dam upstream through the Columbia River and the four lower Snake River dams and reservoirs, were 16.8 days at 28.0 km/d for fish passing the Snake River receiver site near Asotin, and 23.2 days at 21.3 km/d for fish passing the Clearwater River receiver site near the mouth of the river.

Migration rate distributions for salmon in the lower Snake River tended to be skewed to the right with a few fish taking a relatively long time to migrate from dam to dam, but most of the fish passed between dams in less than 1 day (Figure 13). Migration rates of fish through the Lower Granite pool appeared to be slower than through the three downstream pools, but the Lower Granite pool reach includes a few kilometers of the Clearwater River to the receiver at river km 7.5, and Snake River (receiver at river km 237.1). Turbidities may have been higher in the Lower Granite pool and in both of the rivers periodically during the migration season and may have been a factor in the slower migration rate.

Table 3. Mean and median migration rates with 95% confidence intervals for spring and summer chinook salmon with transmitters migrating through reservoirs and in free flowing sections of rivers in the Snake River basin in 1993.

Section of river	Number of fish	Mean travel rates Days	Km/day	Confidence intervals (95%) Days	Km/day	Median travel rates Days	Km/day
Through reservoirs:							
Ice Harbor to Lower Monumental dams	281	1.0	49.9	(0.0-2.3)	(22.8-91.7)	0.9	57.4
Lower Monumental to Little Goose dams	295	0.9	50.3	(0.0-1.9)	(24.0-93.3)	0.8	60.1
Little Goose to Lower Granite dams	274	1.0	59.5	(0.2-1.8)	(33.4-95.9)	0.9	65.3
Lower Granite Dam to Clearwater River site	64	3.0	19.6	(0.0-12.7)	(0.0-75.0)	1.9	31.2
Lower Granite Dam to Snake River site	201	1.5	42.2	(0.1-3.0)	(18.6-78.8)	1.3	50.9
Through rivers:							
Lower Clearwater to Lochsa river sites	17	14.5	10.4	(0.9-28.2)	(0.0-27.7)	15.1	10.0
Snake to Grande Ronde river sites	42	1.9	19.3	(0.0-5.1)	(0.6-58.1)	1.2	29.7
Snake to lower Salmon river sites	156	12.3	16.6	(0.0-27.5)	(0.8-44.5)	9.2	22.4
Snake to Imnaha river sites	24	7.3	12.9	(1.8-12.8)	(3.4-26.3)	7.0	13.6
Lower Salmon to South Fork Salmon sites	79	10.6	12.4	(5.1-16.1)	(6.3-20.3)	10.4	12.6
Lower Salmon to Middle Fork Salmon sites	39	8.9	20.3	(4.2-13.6)	(9.8-33.7)	8.4	21.6

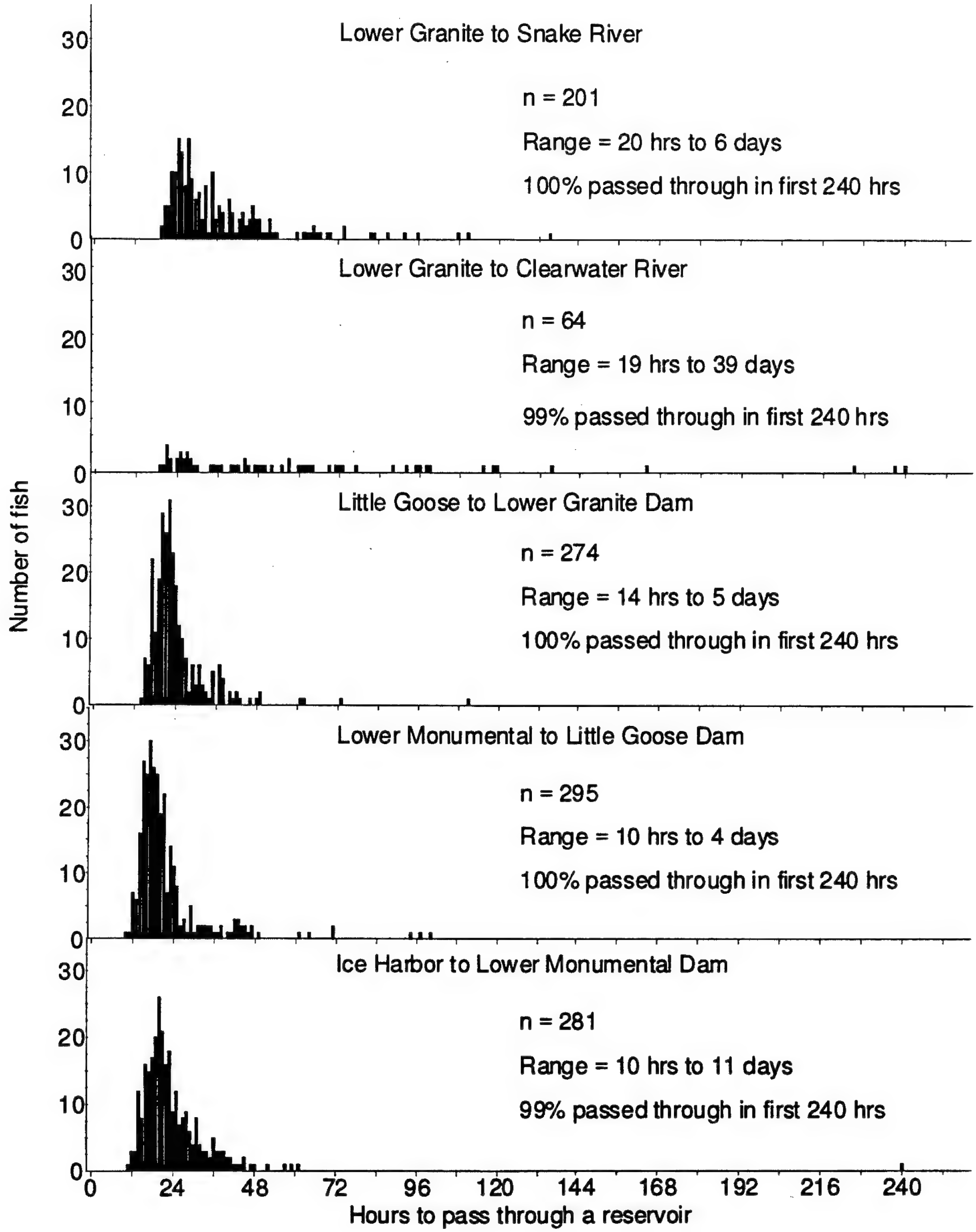


Figure 13. Frequency distribution of time to pass through the four reservoirs in the lower Snake River by spring and summer chinook salmon with radio transmitters in 1993.

Migration rates of fish in the free-flowing sections of the Snake, Clearwater, and Salmon rivers were slower than those of fish in the reservoirs (Table 3). In the free-flowing rivers, salmon migrated at mean rates of 10 to 20 km/d versus an average rate of 53.2 km/d through the three reservoirs between dams, and 44.3 km/d when the Lower Granite Dam to the lower Clearwater River and Snake River fixed receiver sites were included in the average. The slower rates of migration in the free-flowing rivers may have resulted from the higher velocities and turbidities in the rivers compared to the reservoirs.

Chinook Salmon - 1993 Fishway Entrance Use and Passage

In the spring and early summer of 1993 chinook salmon with transmitters were monitored with newly developed instantaneous-scanning receivers (DSP/SRX400) as they approached, entered, and passed through the fishways at each of the lower Snake River dams. The information presented in this section is for the entire migration season with all flow and spill conditions combined.

Ice Harbor Dam

Fishway entrance use and movements within the fishway at Ice Harbor Dam were monitored in the spring and early summer 1993 by recording movements of 340 chinook salmon with transmitters using the new digital spectrum processors (DSP) connected to radio receivers (SRX400). Antennas were placed near each entrance to the fishway, within the fishway, and at the tops of the ladders (Figure 14).

To put passage times at Ice Harbor Dam into perspective, median passage time for chinook salmon from release at John Day Dam to the Ice Harbor Dam tailrace was 5.0 d in 1993, with slightly longer times to pass over the dam (Figure 15). Mean passage times for the same stretches of river were about 8.0 d, but the mean is a less useful descriptor because of the non-normal distribution of passage times.

Median times for passage from the tailrace receiver (about 1 km downstream from the dam) at Ice Harbor Dam to the first recorded approach at an entrance, first entry into the fishway, and exit from the top of the ladder were 0.05, 0.11, and 0.78 d, respectively (Figure 16). The time between passage at the tailrace receiver and first entry into the fishway approached three hours (based on median passage times, Figure 16). Since 1993 was the first year we were able to collect reliable time of passage information on a large number of fish at Ice Harbor Dam, we do not know if two to three hours median time to enter a fishway after entering the tailrace area is normal and acceptable.

The distribution of passage times were skewed to the right with a few fish taking several days to approach the entrances, enter the fishway, or pass over the dam (Figure 16). Mean passage times were longer than median times. Most of the fish entered the fishway within 1-12 hours after passing the tailrace receiver, but several fish took up to 4 d to pass the dam because they spent a day or more in the fishway or time exiting and re-entering the fishway. Some of the time spent in the fishway was at night when the fish temporarily discontinued their upstream migration, but some of the time was spent by fish migrating up and down the powerhouse collection channel during daylight (Figure 17). The passage time between the tailrace and the top of the ladder also includes the time when fish exited the fishway via one of the entrances, moved out into the tailrace, and then re-entered the fishway.

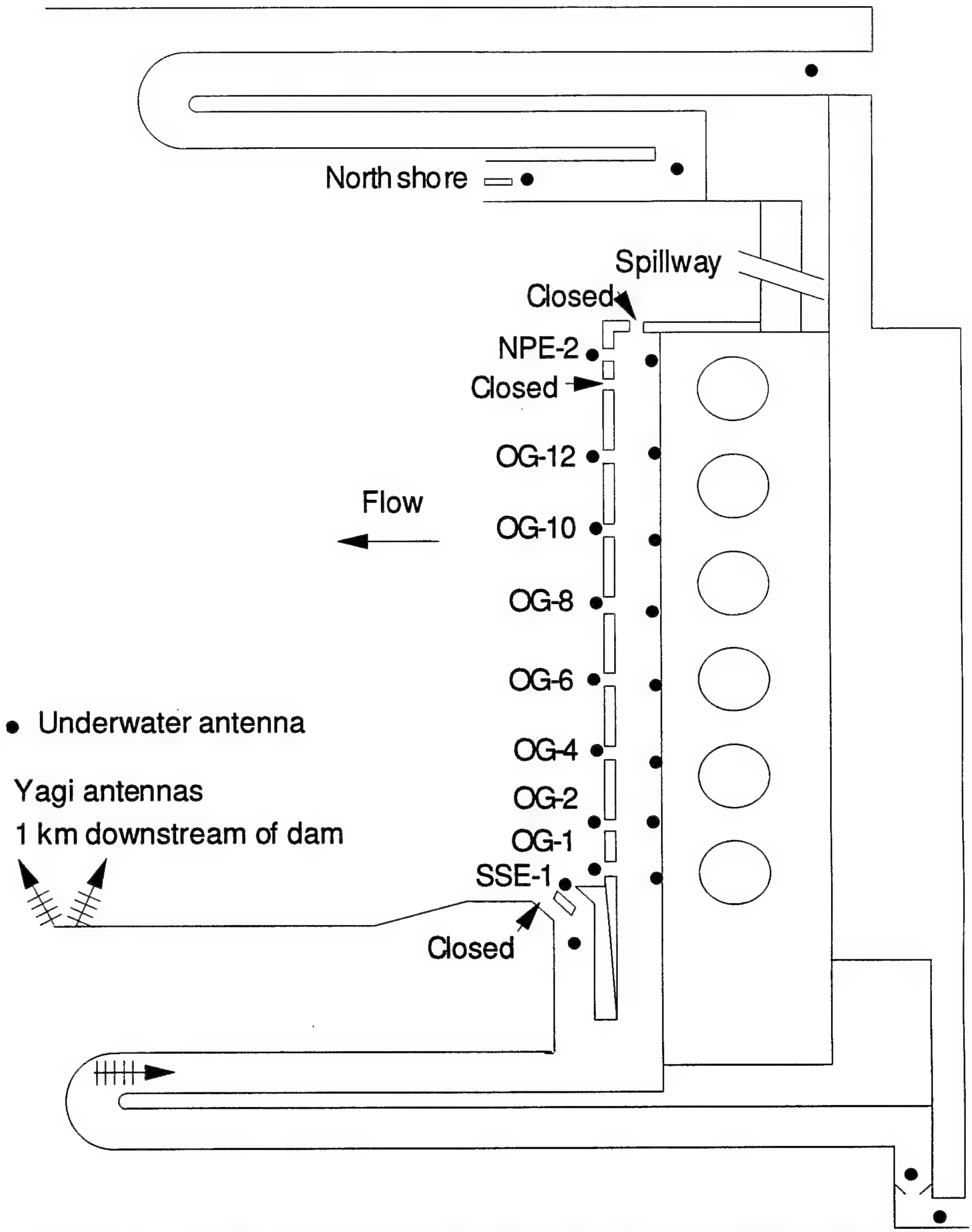


Figure 14. Location of antennas and fishway entrances at Ice Harbor Dam in the spring and early summer of 1993 when chinook salmon were passing the dam.

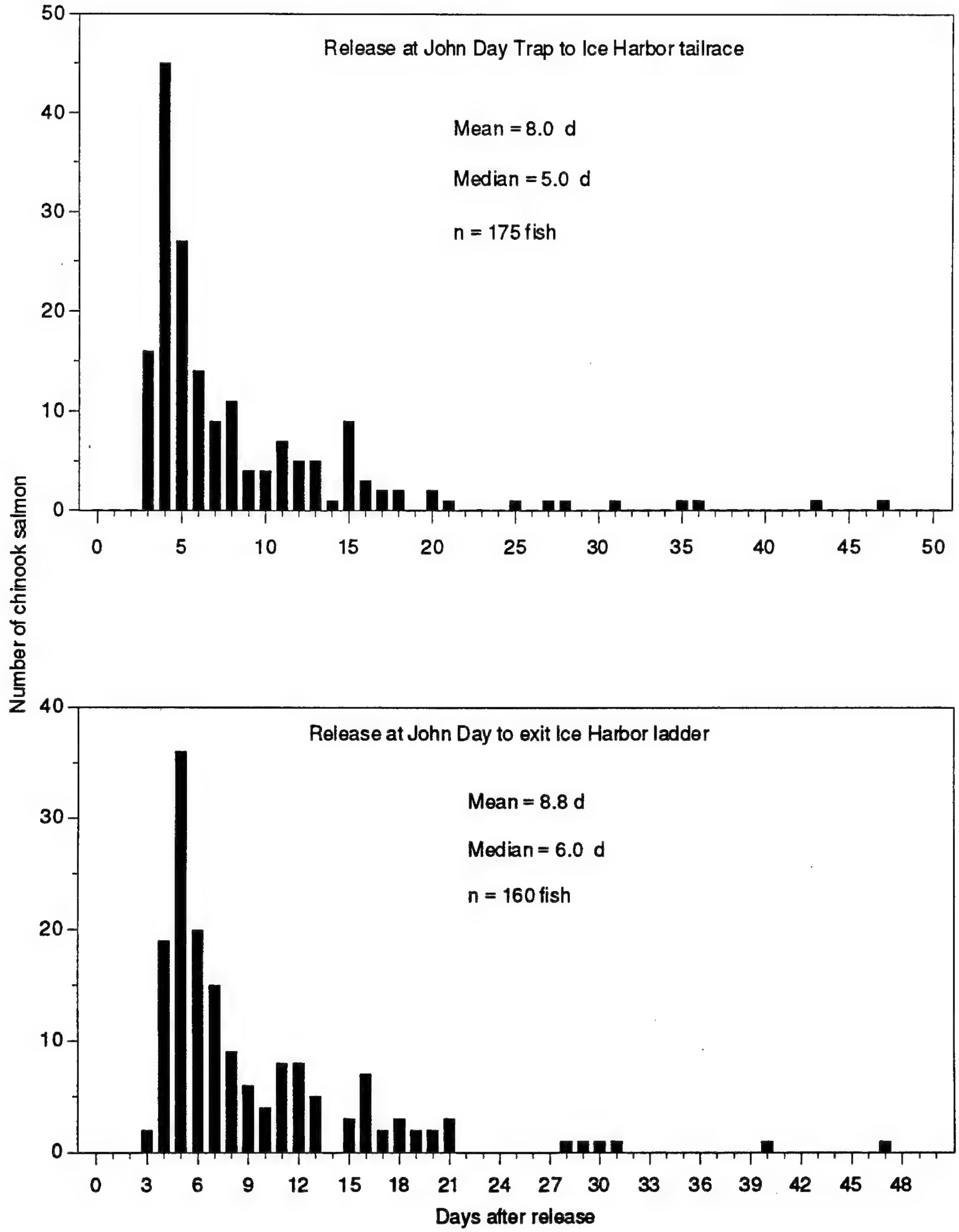


Figure 15. Distribution of number of chinook salmon and days to migrate from the release site in the John Day Dam ladder to the tailrace and to exit from the top of the ladder at Ice Harbor Dam in the spring and early summer 1993.

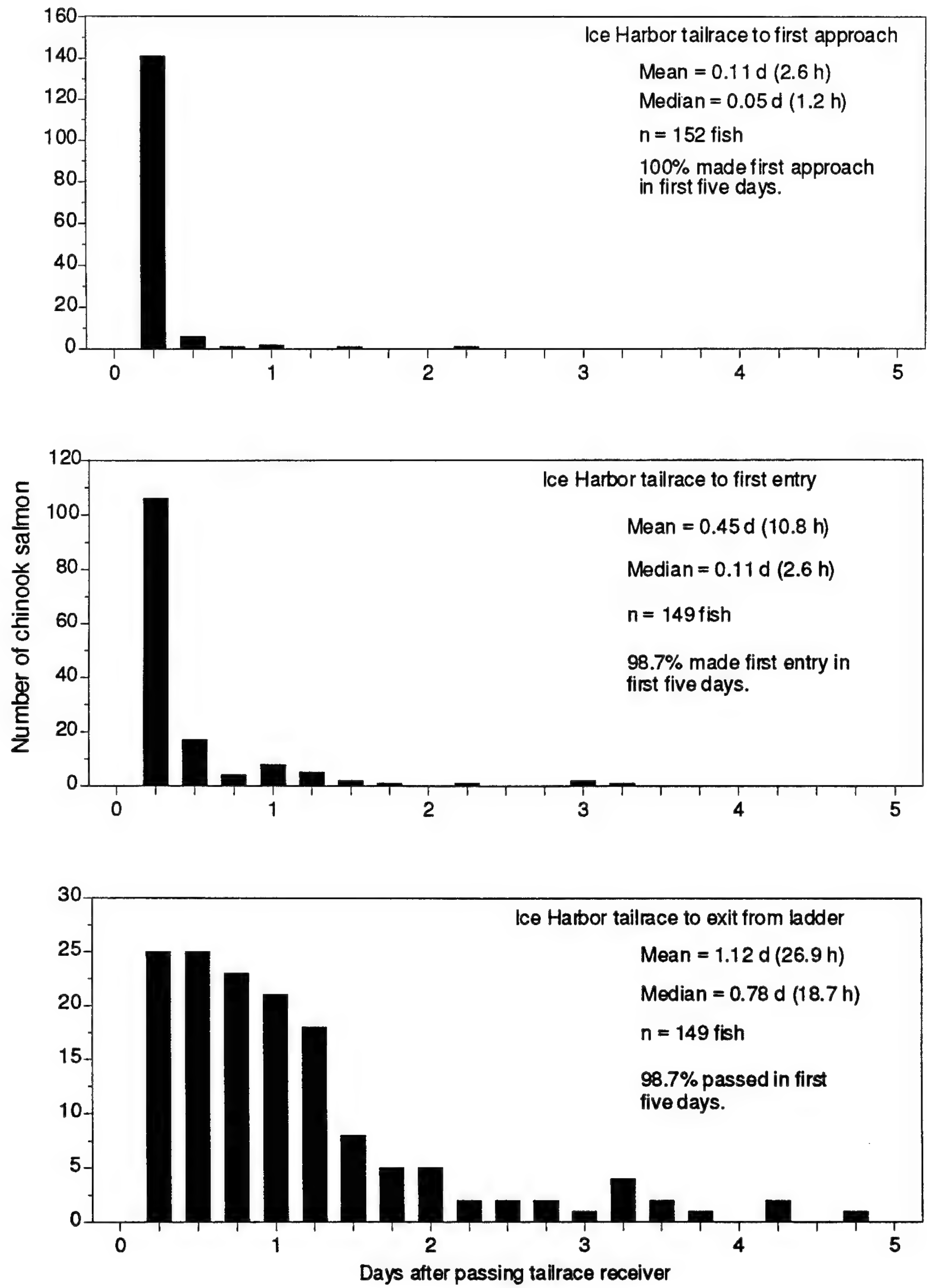


Figure 16. Distribution of numbers of chinook salmon and days to pass from the Ice Harbor Dam tailrace to first approach at a fishway entrance, first entry into the fishways, and exit from the top of the ladders in spring and early summer 1993.

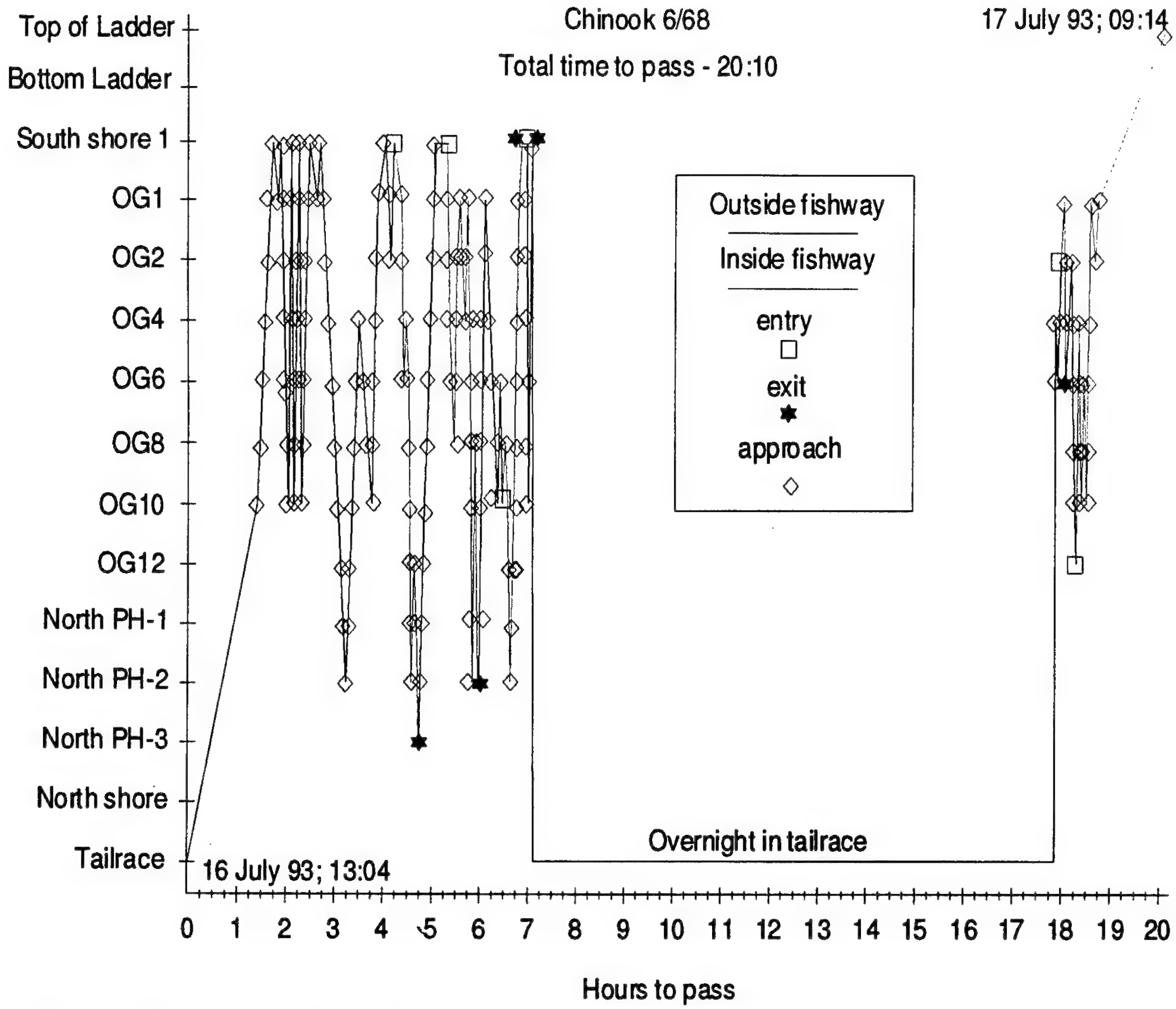
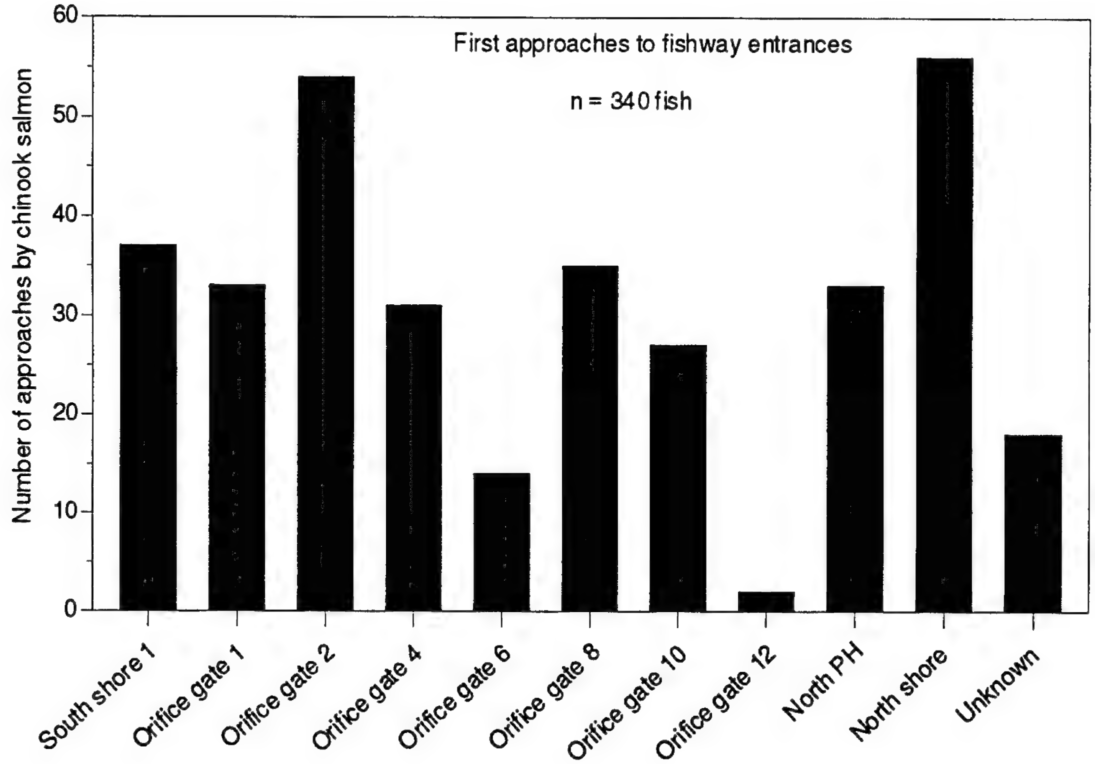


Figure 17. Diagram of the types of movements made by some chinook salmon in the spring and early summer 1993 that took several hours to approach the fishways at Ice Harbor Dam and pass through the fishway.

First approaches to the fishway at Ice Harbor Dam by chinook salmon occurred at all entrances (with fewer at OG-6 and -12) (Figure 18). The first approaches at the north shore and NPE-2 entrances are evidence that significant numbers of fish move up to the dam north of the powerhouse, perhaps circle through the spillway stilling basin, and pass by the NPE-2 entrance before entering the fishway.

When all the approaches at fishway entrances made by chinook salmon in the spring and early summer 1993 are considered, chinook salmon concentrated at the south end of the powerhouse at the SSE-1 entrance and at orifice gates 1 and 2 (Figure 18). The large number of approaches to entrances (30 per fish on average, 10,100 total) is an indication that chinook salmon were hesitant to enter the fishway and moved back and forth along the dam before entering the fishway. About 37% of the 340 chinook salmon



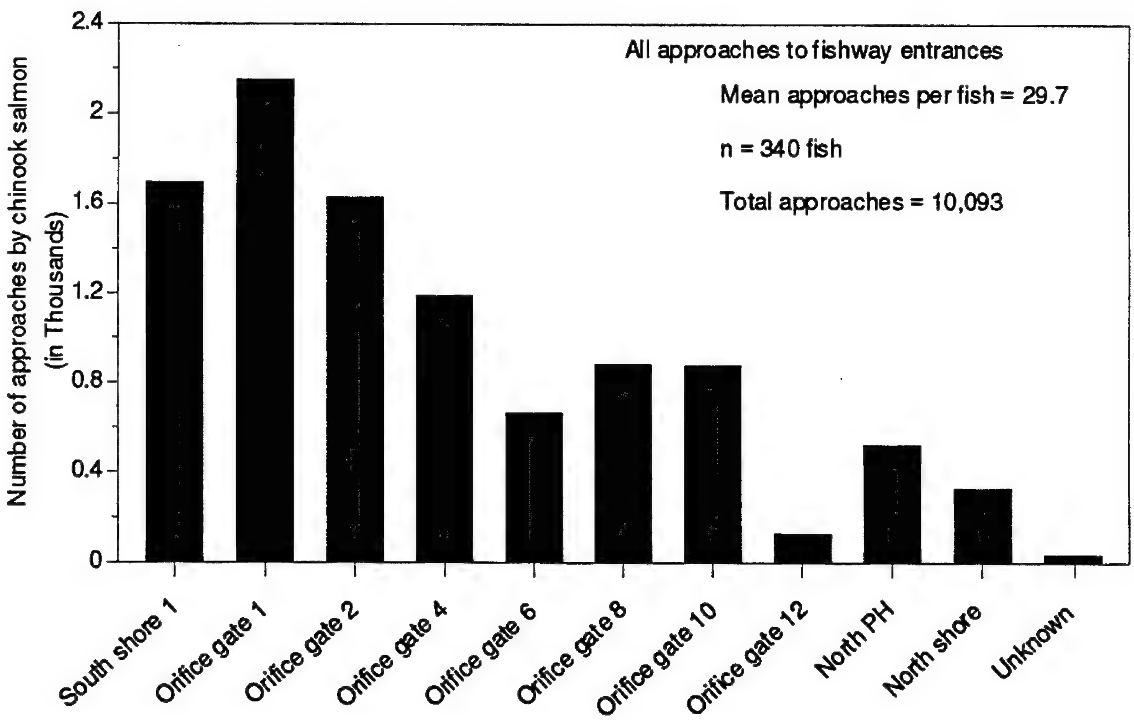


Figure 18. Number of first and total approaches at fishway entrances at Ice Harbor Dam by chinook salmon in the spring and early summer 1993.

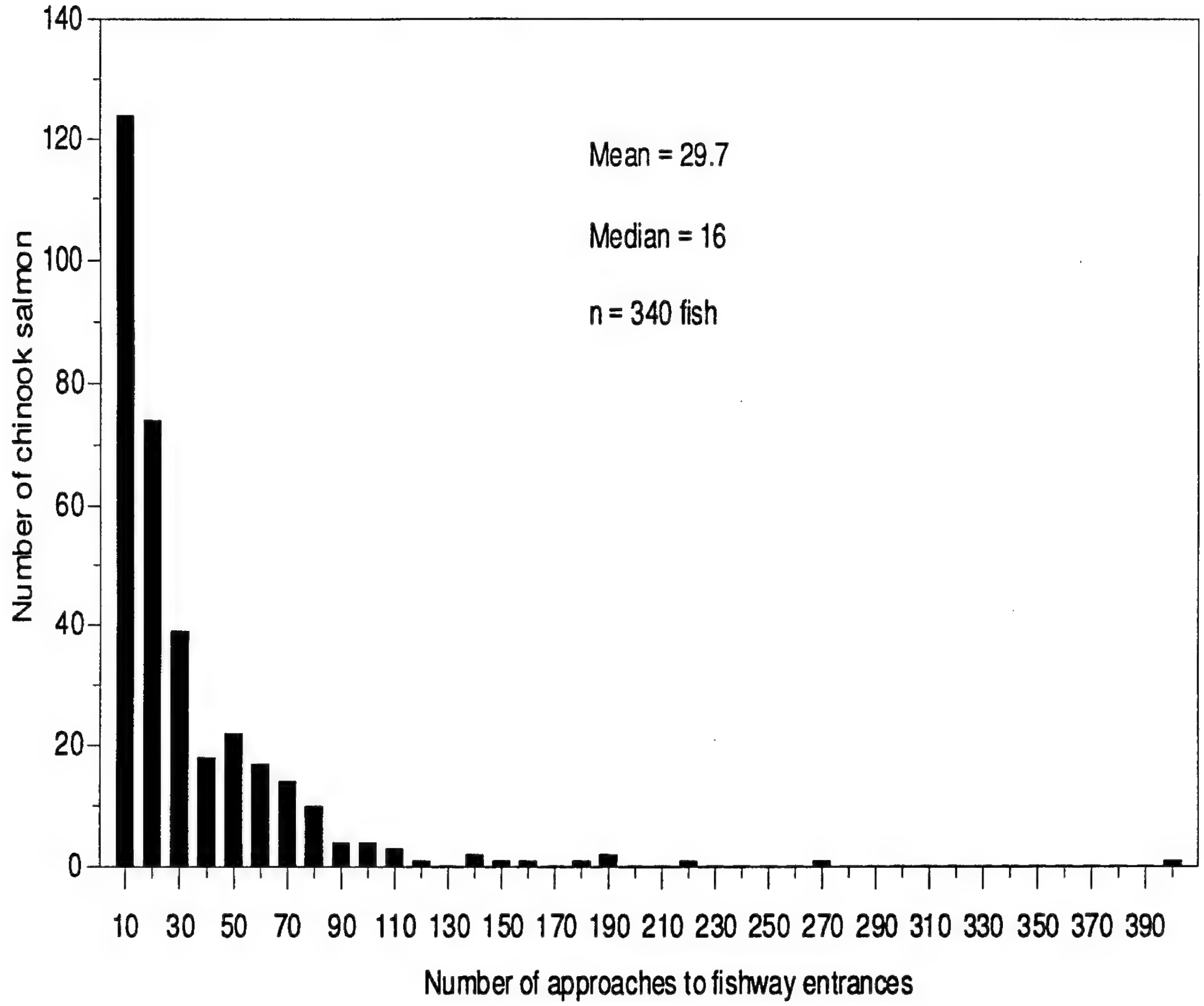


Figure 19. Number of chinook salmon approaching fishway entrances one or more times at Ice Harbor Dam in spring and early summer 1993.

monitored, approached the dam 10 or fewer times, but several fish approached various entrances 30 or more times (Figure 19).

The entrances to the fishway used by chinook salmon in the spring and early summer 1993 were more limited than the entrances approached. For example, a majority of the first and repeated entries into the fishway occurred at the SSE-1, NPE-2, and north shore entrances (Figure 20), despite first approaches to the fishways that were more or less uniformly distributed at most entrances (Figure 18). Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those openings. The location of discharges from the dam was an important factor in where fish approached the dam, but not the only factor as illustrated by the higher than average numbers of fish

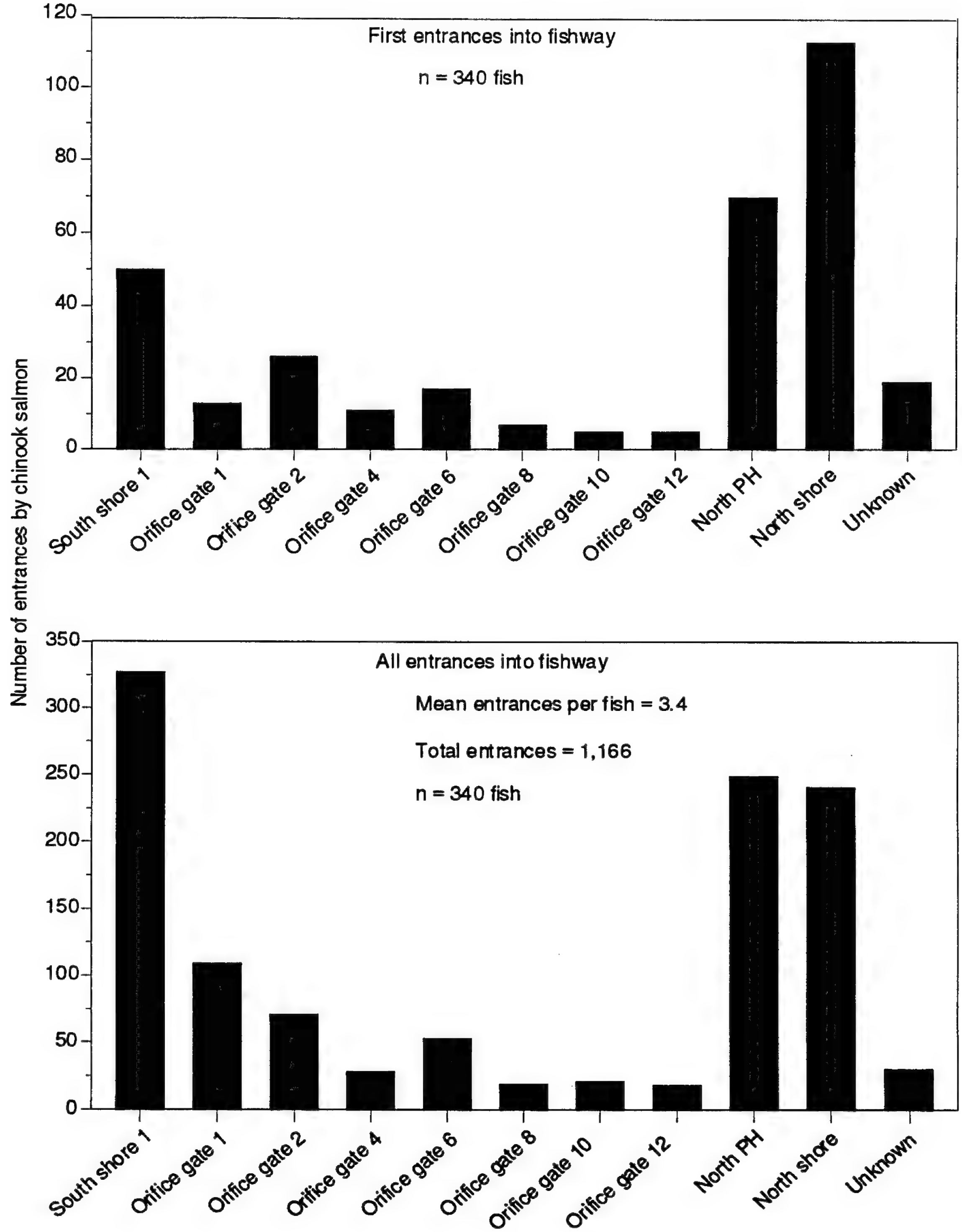


Figure 20. Number of first and total entries by chinook salmon into the Ice Harbor Dam fishway via each entrance in spring and early summer 1993.

that approached the dam and entered the fishway at the NPE-2 and north shore entrances where there was no flow (except during spill) to attract the fish other than that coming from the fishway. The discharges from the NPE-2 and north shore entrances may have been easier for chinook salmon to find and follow to the entrances when there was no spill. The relatively low use of the orifice-gate entrances may have been caused by the small discharges (design of 60 cfs) from those entrances relative to the turbine discharges, and the size and depth of the openings may not have been as attractive as other entrances. The orifice-gate entrances at Ice Harbor Dam are 2 feet high and 6 feet wide, with the top of the opening 4.5 feet down from the water surface. SSE-1, NPE-2, and the north shore entrances are 12 foot wide vertical weir gates.

Most chinook salmon (146 of 340 monitored, 43%) entered the fishways at Ice Harbor Dam only once (Figure 21). About one-half of the fish entered two or more time. About one-half of the salmon that entered the fishway did not exit (fallout) from the fishway through any of the entrances, and the remainder left the fishways through the entrances 1 to 27 times. Chinook salmon exited from the fishways via all of the entrances, but most exits were at the NPE-2, north shore, and SSE-1 entrances (Figure 22).

Net entry rates (entrances minus exits) for the fishway entrances ranged from about 55 to -10 for the first entries and exits, and 100 to -130 for all entries and exits (Figure 23). Overall, the north shore entrance was the most effective entrance followed by OG-1 and -2, and SSE-1. There were more exits than entries of chinook salmon at the NPE-2 entrance.

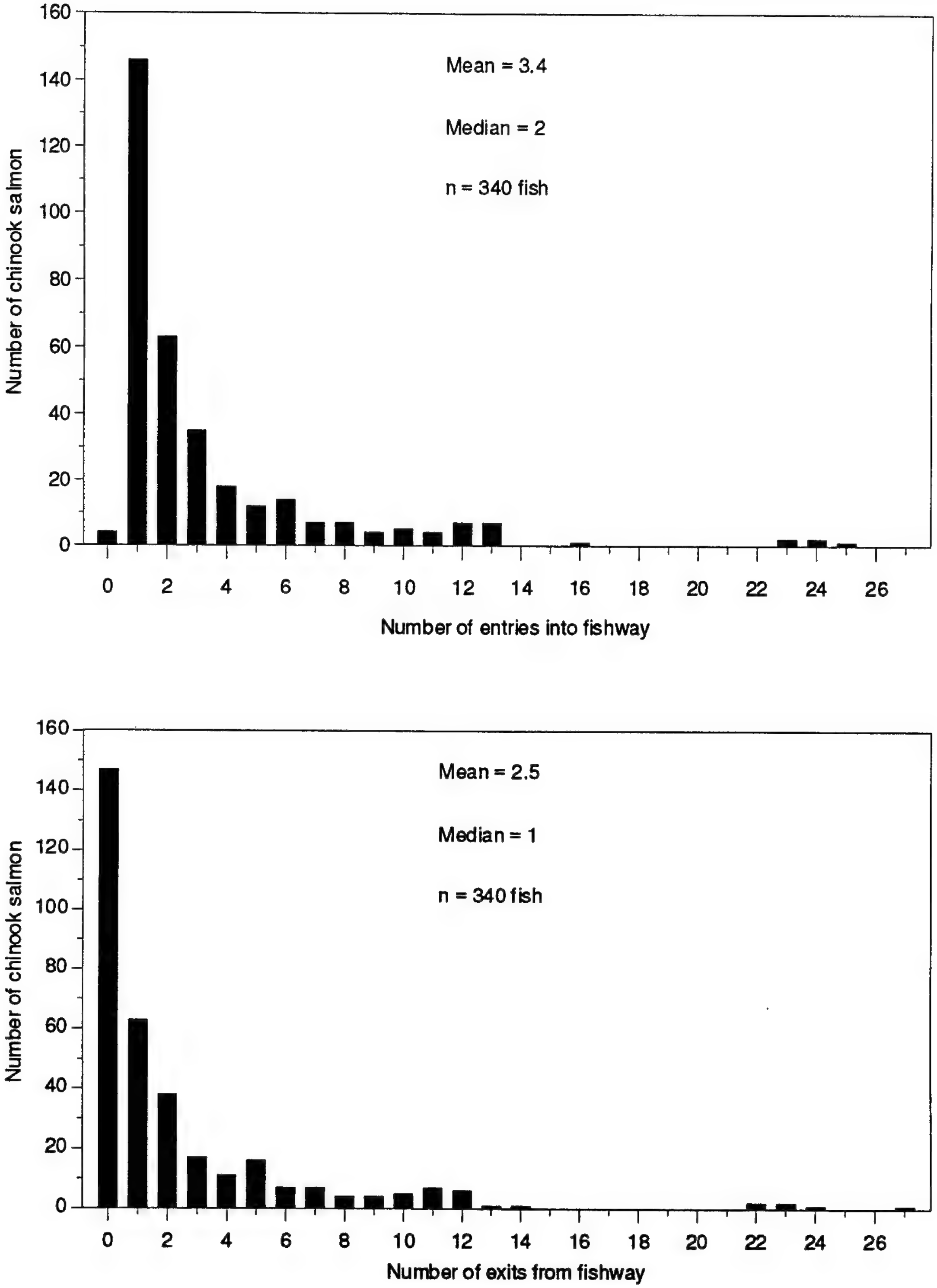


Figure 21. Number of chinook salmon that did not enter or exit, and those with multiple entries and exits into or from the fishway at Ice Harbor Dam via the entrances in spring and early summer 1993.

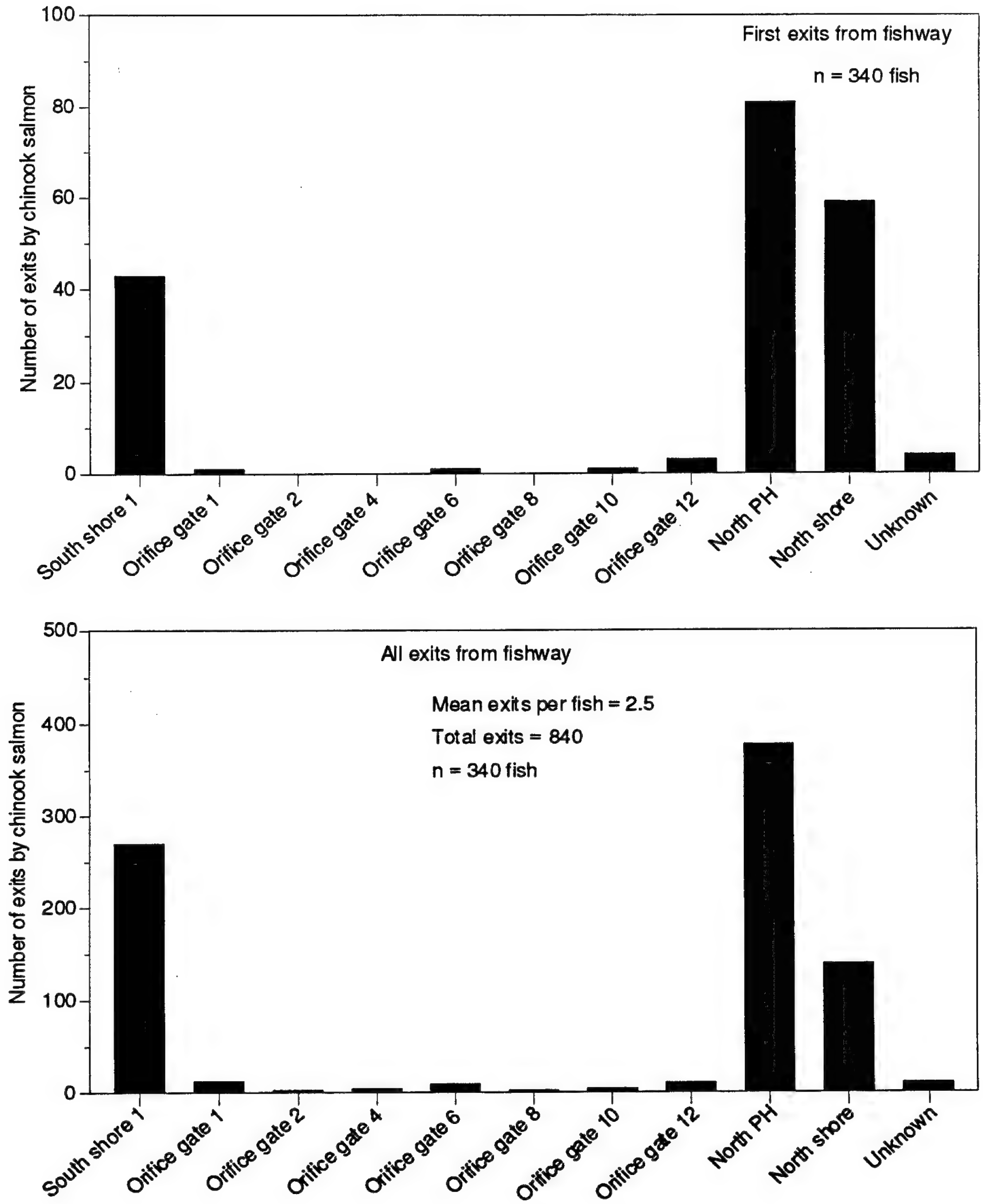


Figure 22. Number of first and total exits from fishway for each entrance by chinook salmon at Ice Harbor Dam in spring and early summer 1993.

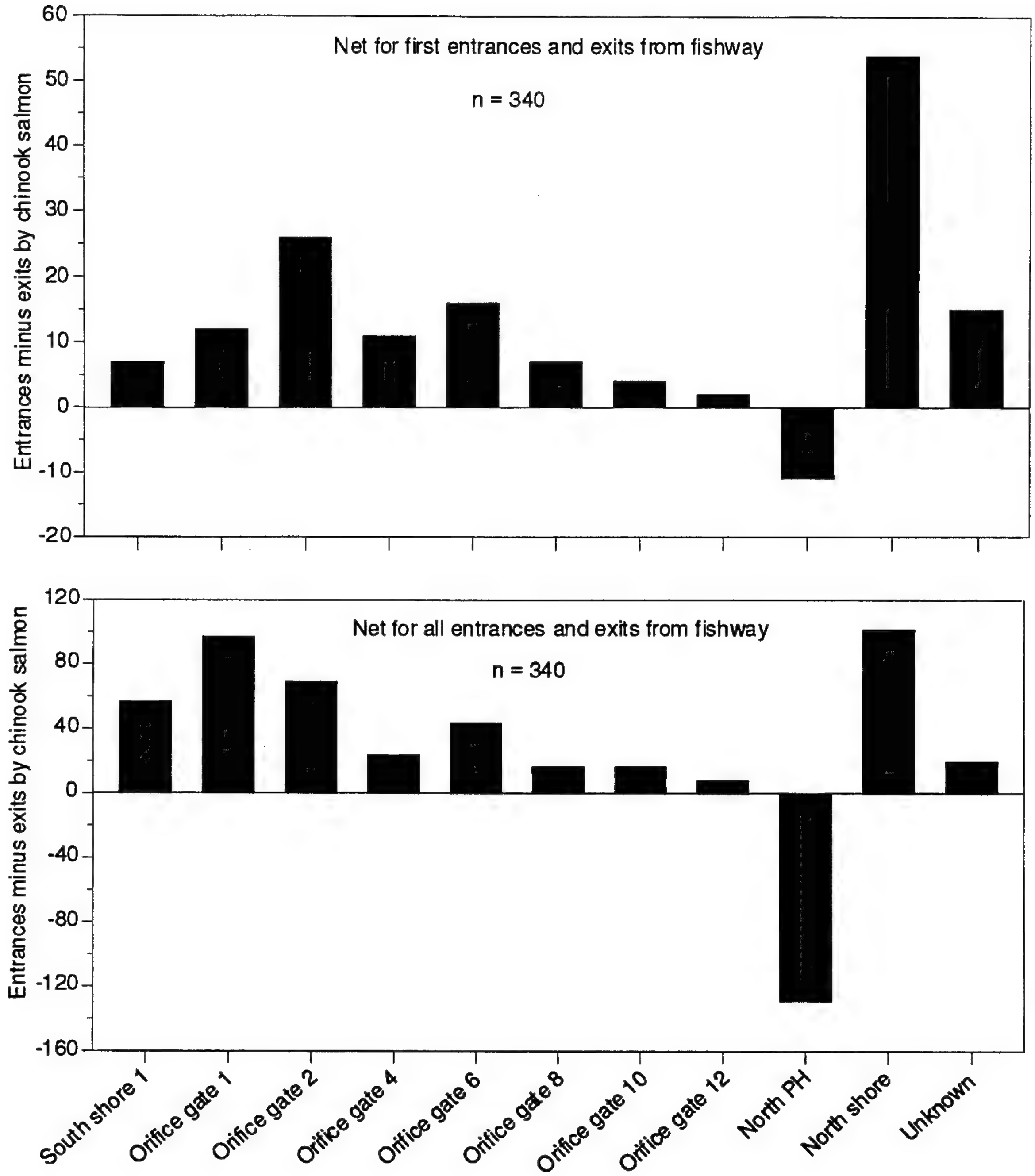


Figure 23. Net number of first and total exits from fishway for each entrance by chinook salmon at Ice Harbor Dam in spring and early summer 1993.

Lower Monumental Dam

Fishway entrance use and movements within the fishway at Lower Monumental Dam were monitored in the spring and early summer of 1993 by recording movements of 310 chinook salmon with transmitters using the new digital spectrum processors connected to radio receivers. Antennas were placed near each entrance to the fishway, within the fishway, and at the top of the ladder (Figure 24). Median times for passage from the tailrace receiver (about 1 km downstream from the dam) at Lower Monumental Dam to the first recorded approach at an entrance, first entry into the fishway, and exit from the top of the ladder were 0.08, 0.19, and 0.85 d, respectively, (Figure 25). The time between passage at the tailrace receiver and first entry into the fishway was nearly five hours (based on median passage times, Figure 25). Since 1993 was the first year we were able to collect reliable time of passage information on a large number of fish, we do not know if four to five hours median time to enter a fishway after passing into the tailrace is normal, and an acceptable time.

The distribution of passage times were skewed to the right with a few fish taking several days to approach the entrances, enter the fishway, or pass over the dam (Figure 25). Mean passage times were longer than median times. Most of the fish entered the fishway within 24 hours after passing the tailrace receiver, but several fish took up to 3 d to pass the dam because they spent a day or more in the fishway or time exiting and re-entering the fishway. Some of the time spent in the fishway was at night when the fish temporarily discontinued their upstream migration, but some of the time was spent by fish migrating up and down the powerhouse collection channel during daylight (Figure 26). The passage time between the tailrace and the top of the ladder also includes some fish that exited the fishway via one of the entrances, moved out into the tailrace, and then re-entered the fishway.

Most chinook salmon first approached the fishways at Lower Monumental Dam at the northern end of the powerhouse (OG-1 and -3), and at SPE-2 (Figure 27). The first approaches at SPE-2 is an indication that significant numbers of fish move up to the dam south of the powerhouse, perhaps circle through the spillway stilling basin, and pass by the SPE-2 entrance before entering the fishway. Less than 10% of the chinook salmon approached the fishways first at the south or north shore entrances.

When all the approaches at fishway entrances made by chinook salmon in the spring and early summer of 1993 are considered, most of the approaches by chinook salmon were at the north end of the powerhouse from OG-7 to OG-1, but 15% of all approaches were at SPE-2 (Figure 27). The large number of approaches to entrances (58 per fish on average, 17,900 total) is an indication that chinook salmon were somewhat hesitant to enter the fishway and moved back and forth along the dam before entering the fishway. About 20% of the 310 chinook salmon monitored, had approached the dam 10 or fewer times, but several fish approached various entrances 100 or more times (Figure 28).

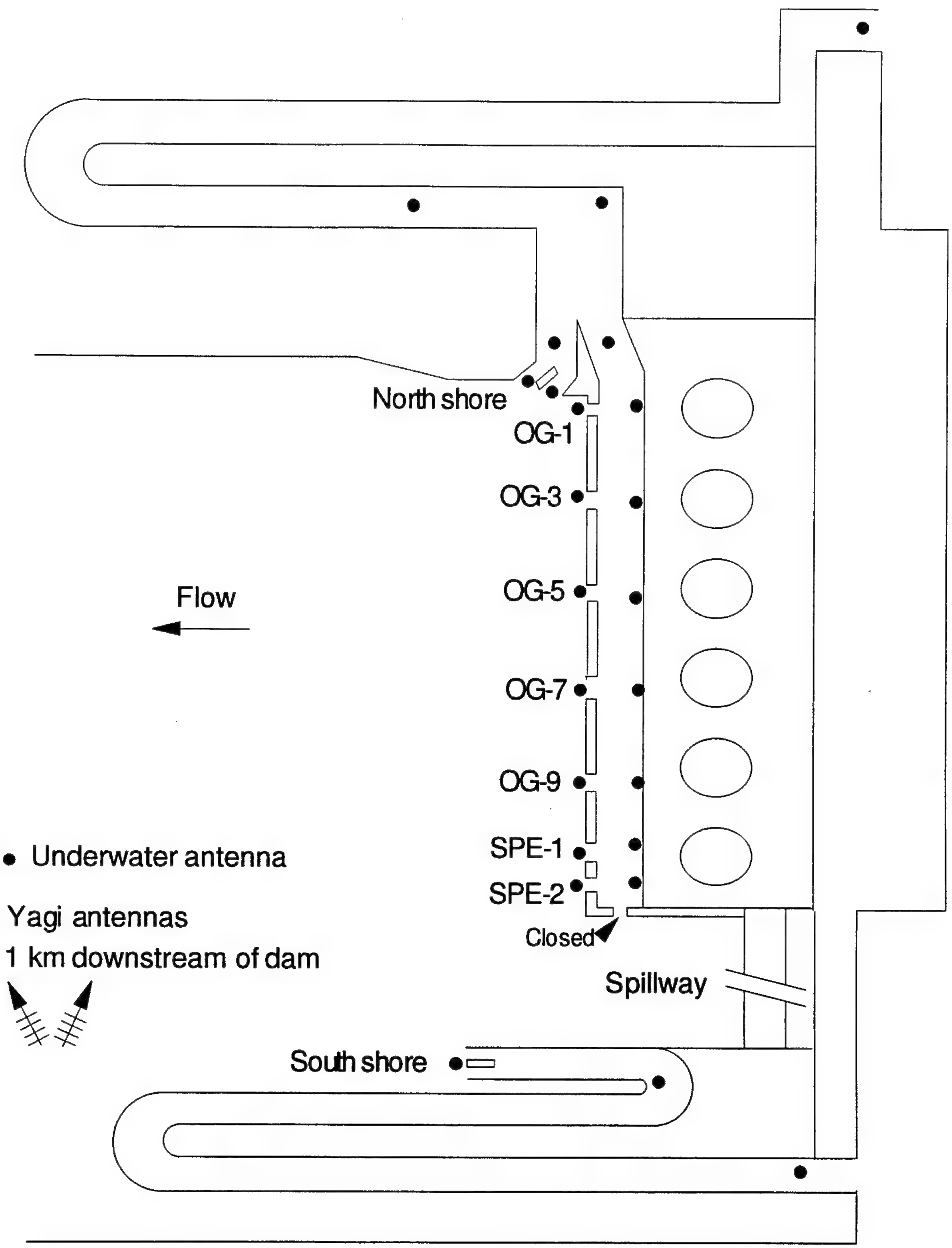


Figure 24. Location of antennas and fishway entrances at Lower Monumental Dam in the spring and early summer when chinook salmon were passing the dam in 1993.

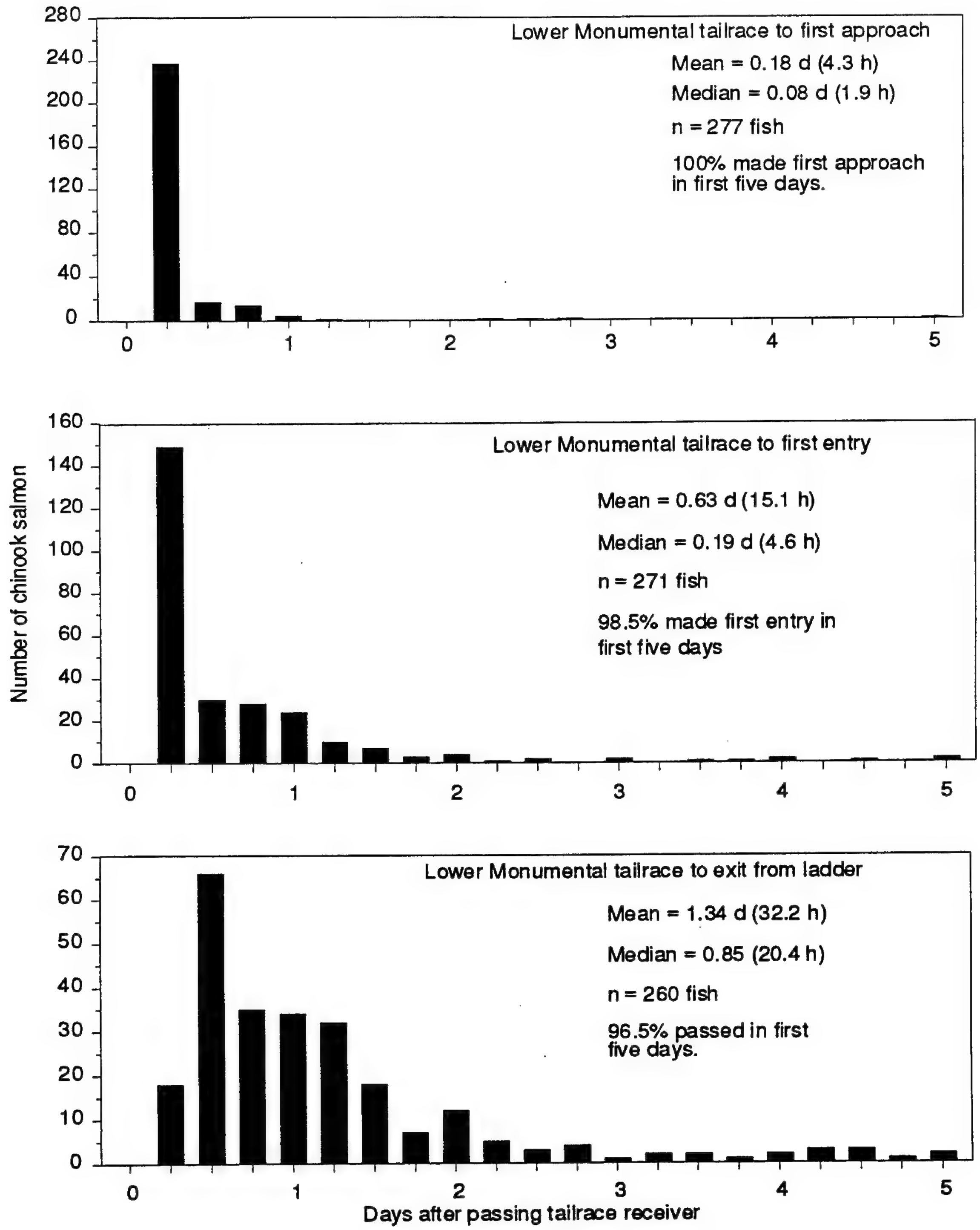


Figure 25. Distribution of numbers of chinook salmon and days to pass from the Lower Monumental Dam tailrace to first approach at a fishway entrance, first entry into the fishway, and exit from the top of the ladder in spring and early summer 1993.

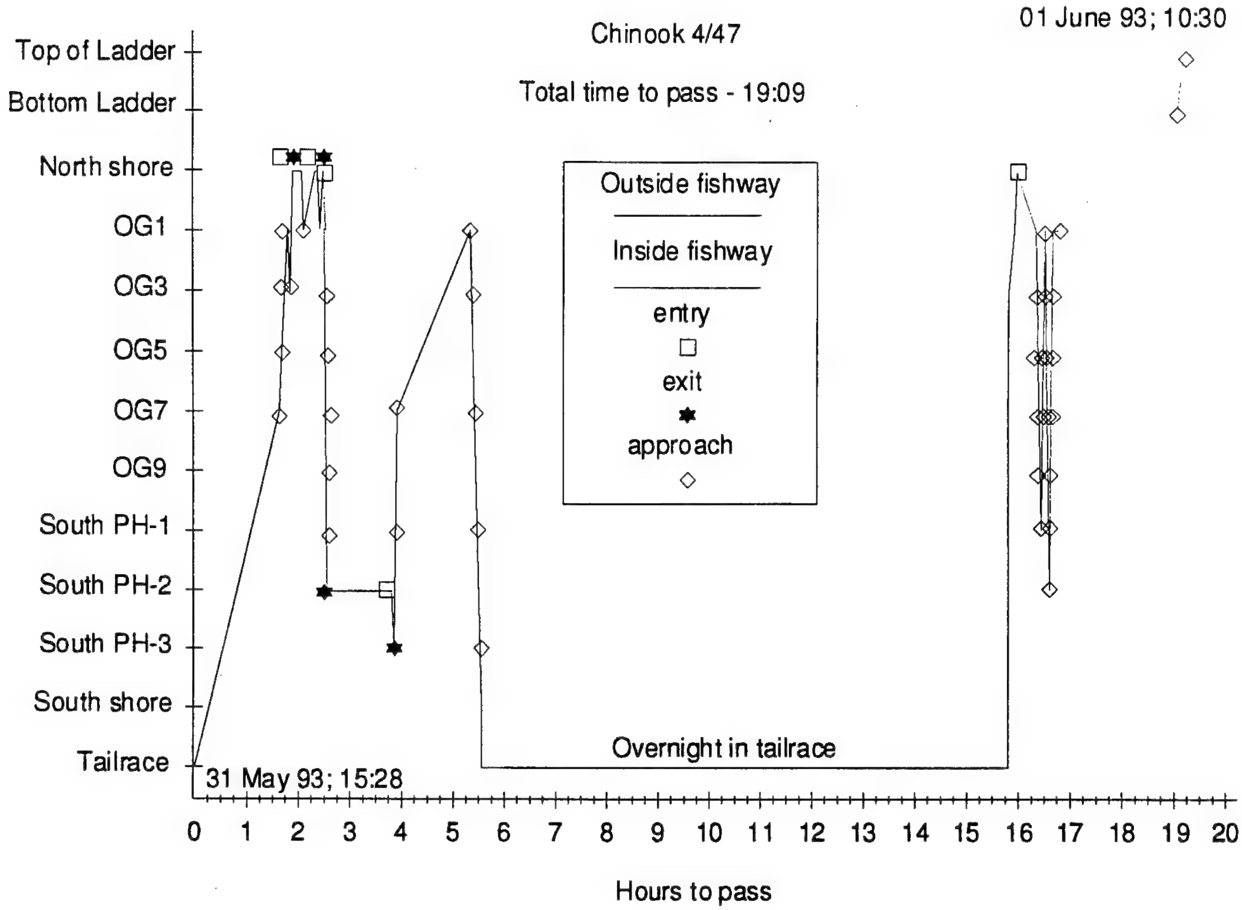


Figure 26. Diagram of the type of movements made by some chinook salmon in the spring and early summer of 1993 at Lower Monumental Dam when approaching the dam and passing through the fishway.

The entrances to the fishway used by chinook salmon in the spring and early summer of 1993 at Lower Monumental Dam were more limited than the entrances approached. For example, a majority of the first and repeated entries into the fishway occurred at the south shore, SPE-2 and -1, and north shore entrances (Figure 29), despite the large number of approaches to the fishway at the floating orifice-gate entrances (Figure 27). Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those openings. The location of discharges from the dam was an important factor in where fish approached the dam, but not the only factor as illustrated by the higher than average numbers of fish that approached the dam and entered the fishway at the SPE-1 and -2 and south shore entrances where there was no flow (except during spill) to attract the fish other than that coming from the fishway. The relatively low use of the orifice-gate entrances may have resulted because discharges (design of 60 cfs) from those entrances mixed with the discharges from the turbines, the discharge was not attractive to the fish (volume and velocity), and the size and depth of the orifice-gate openings may not have been as attractive as other openings. The orifice

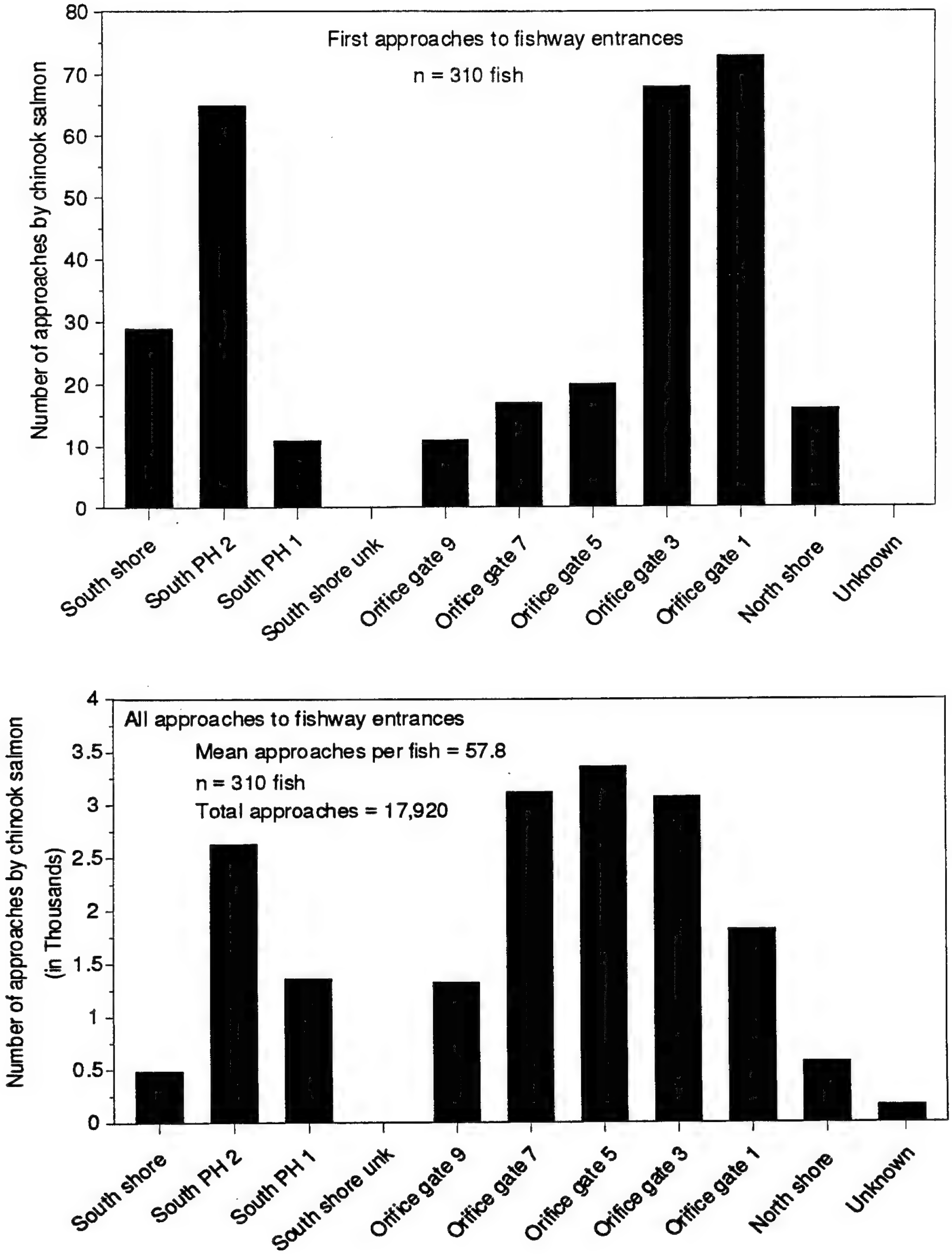


Figure 27. Number of first and total approaches at fishway entrances at Lower Monumental Dam by chinook salmon in the spring and early summer of 1993.

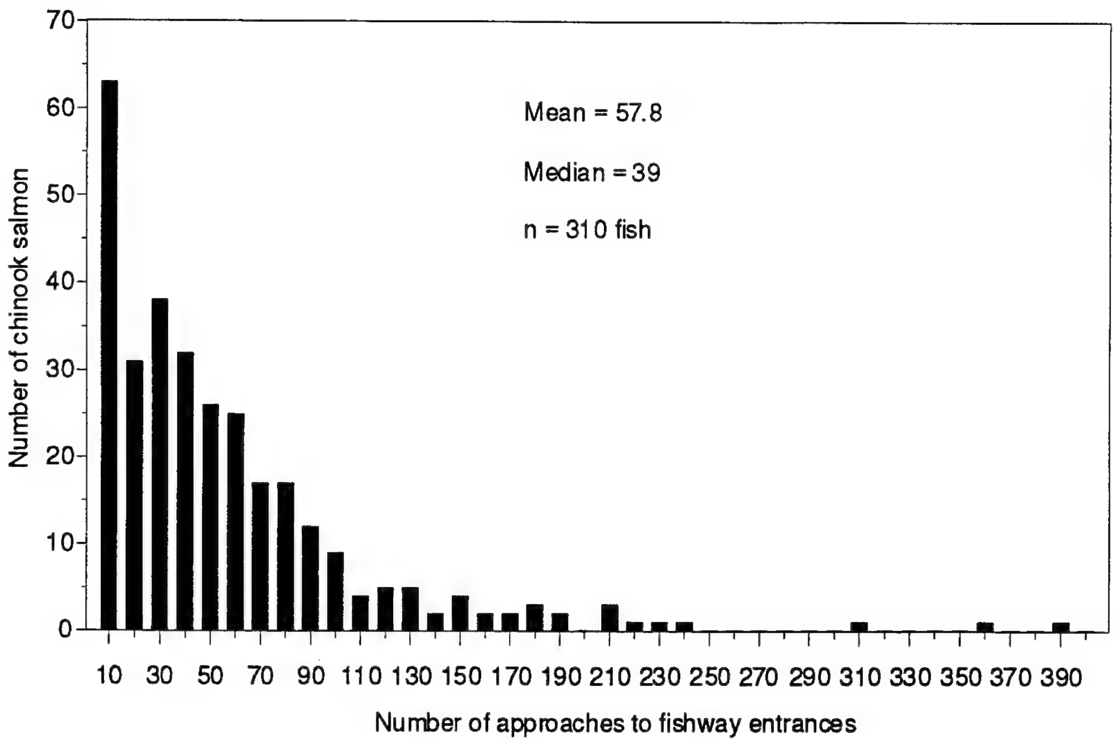


Figure 28. Number of chinook salmon approaching fishway entrances one or more times at Lower Monumental Dam in spring and early summer 1993.

gate entrances at Lower Monumental Dam are 2 feet high and 6 feet wide, with the top of the opening 4 feet down from the water surface. The south shore entrance is comprised of two 6-foot-wide vertical slots, the north shore entrance of two 4-foot-wide vertical slots, and south PH-1 and -2 are both six-foot-wide vertical weir gates. The depth of vertical weir gates is adjustable for tailrace conditions, but are generally set at about 8 feet deep.

Many chinook salmon (107 of 310 monitored, 35%) entered the fishway at Lower Monumental Dam only once (Figure 30). About two-thirds of the fish entered two or more times. One-third of the chinook salmon that entered the fishway did not exit the fishway via any of the entrances, and the remainder exited the fishway 1 to 32 times.

Chinook salmon exited from the fishway via all of the entrances, but more did so at the south shore, SPE-1 and -2, and north shore entrances (Figure 31). A high exit rate had been observed at the south powerhouse entrances (Turner et al. 1982). Net entry rates (entrances minus exits) for the fishway entrances ranged from about 65 to -15 for first entries and exits, and 122 to -60 for all entries and exits (Figure 32). The south shore entrance was the most effective entrance followed by the north shore, and OG-9 and -5. Overall, there were more exits than entries of chinook salmon at the SPE entrances. Entries exceeded exits at the remainder of the entrances to the fishway.

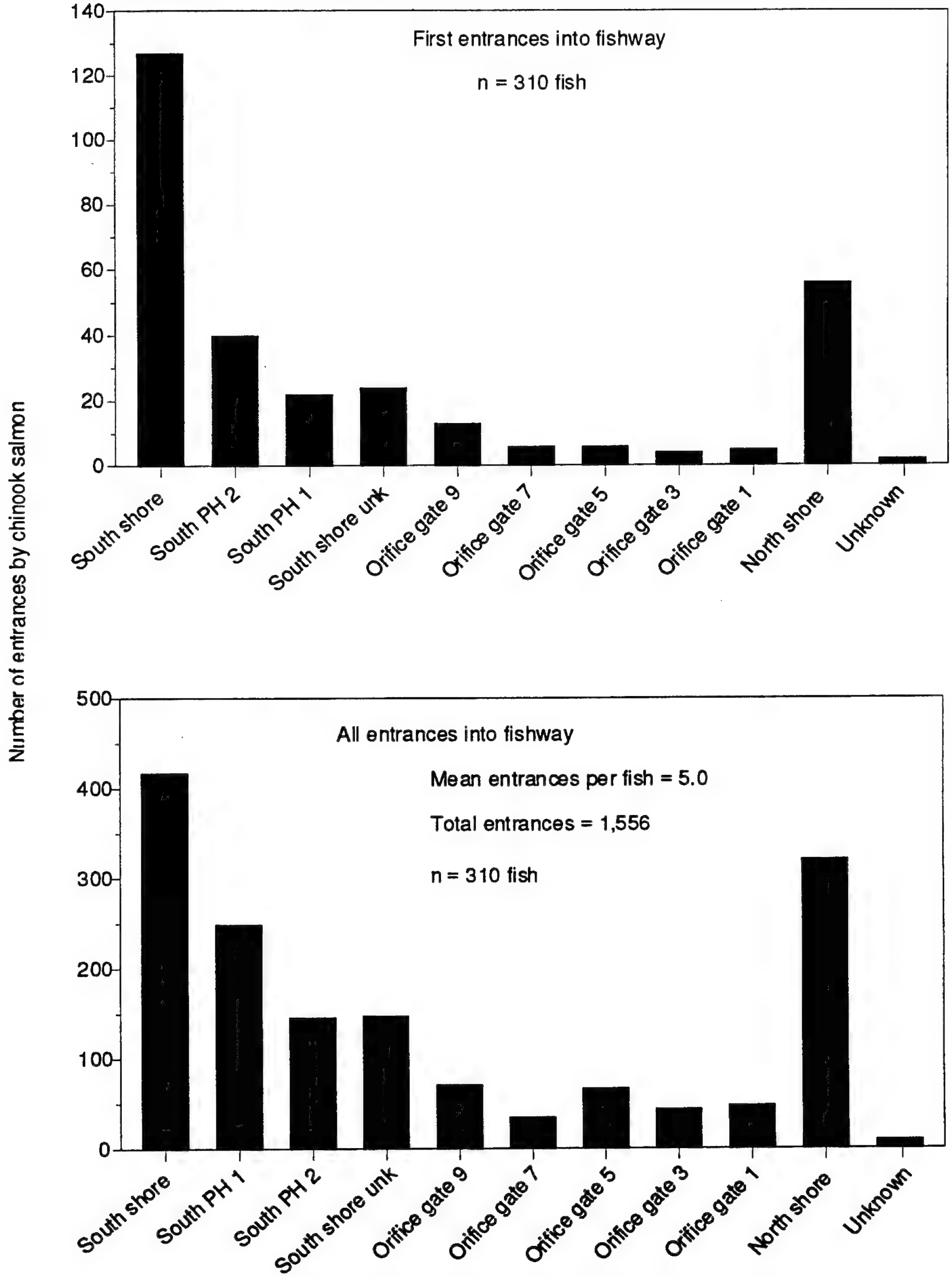


Figure 29. Number of first and total entries by chinook salmon into the Lower Monumental Dam fishway via each entrance in spring and early summer 1993.

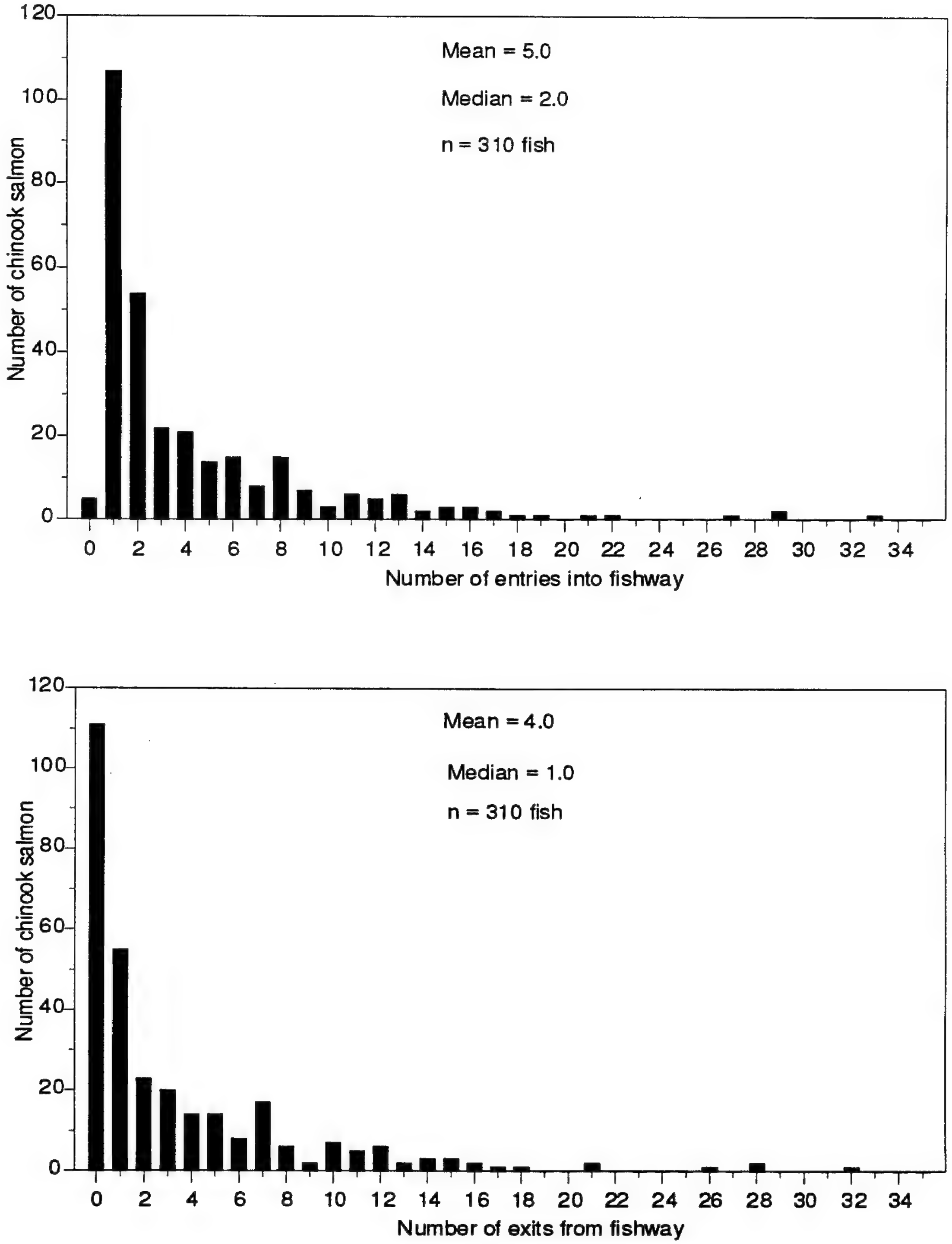
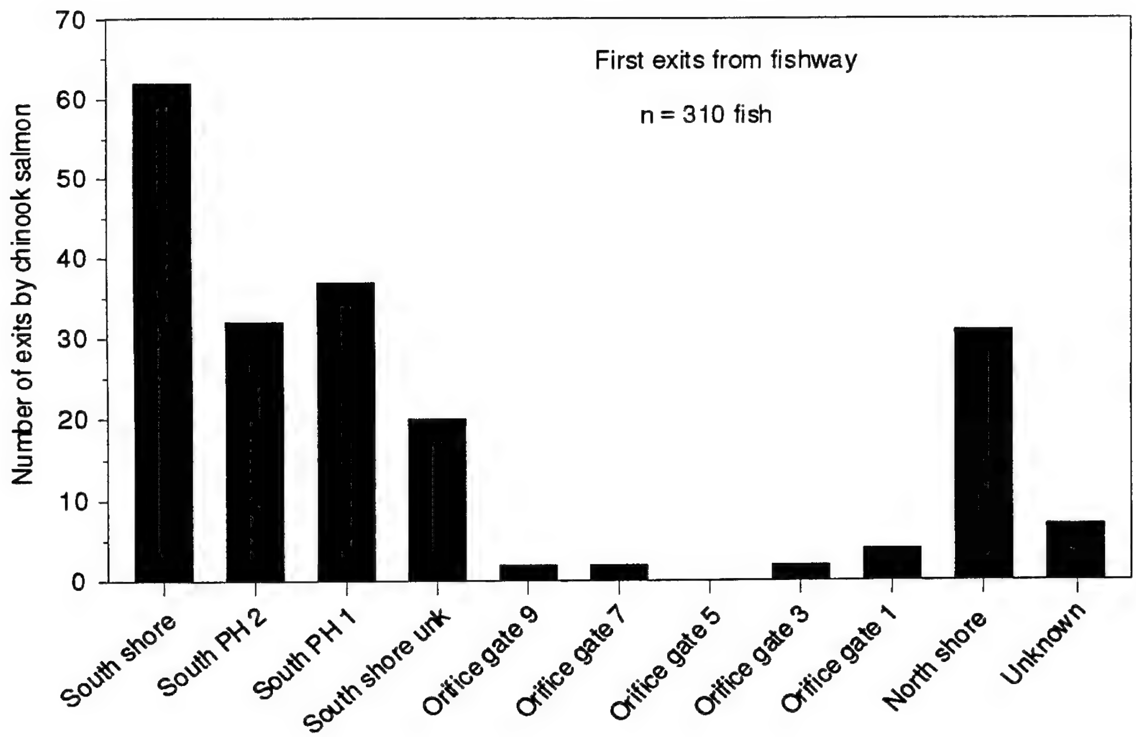


Figure 30. Number of chinook salmon that did not enter or exit, and those with multiple entries and exits into or from the fishway at Lower Monumental Dam via the entrances in spring and early summer 1993.



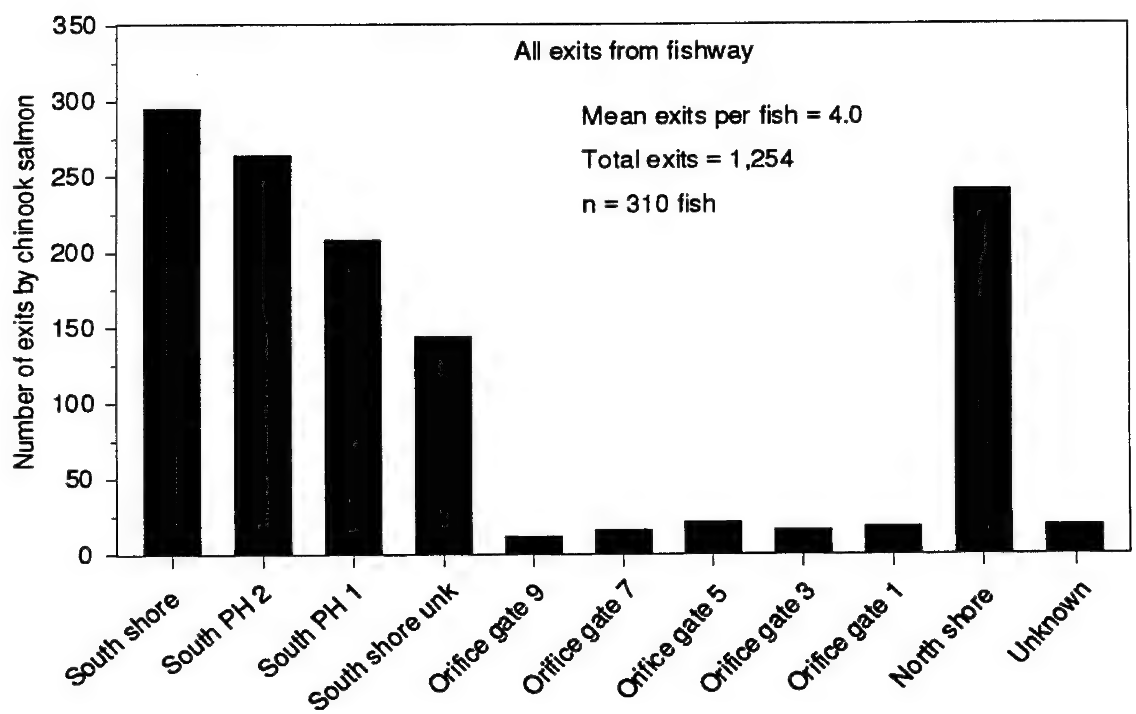


Figure 31. Number of first and total exits from fishway for each entrance by chinook salmon at Lower Monumental Dam in spring and early summer 1993.

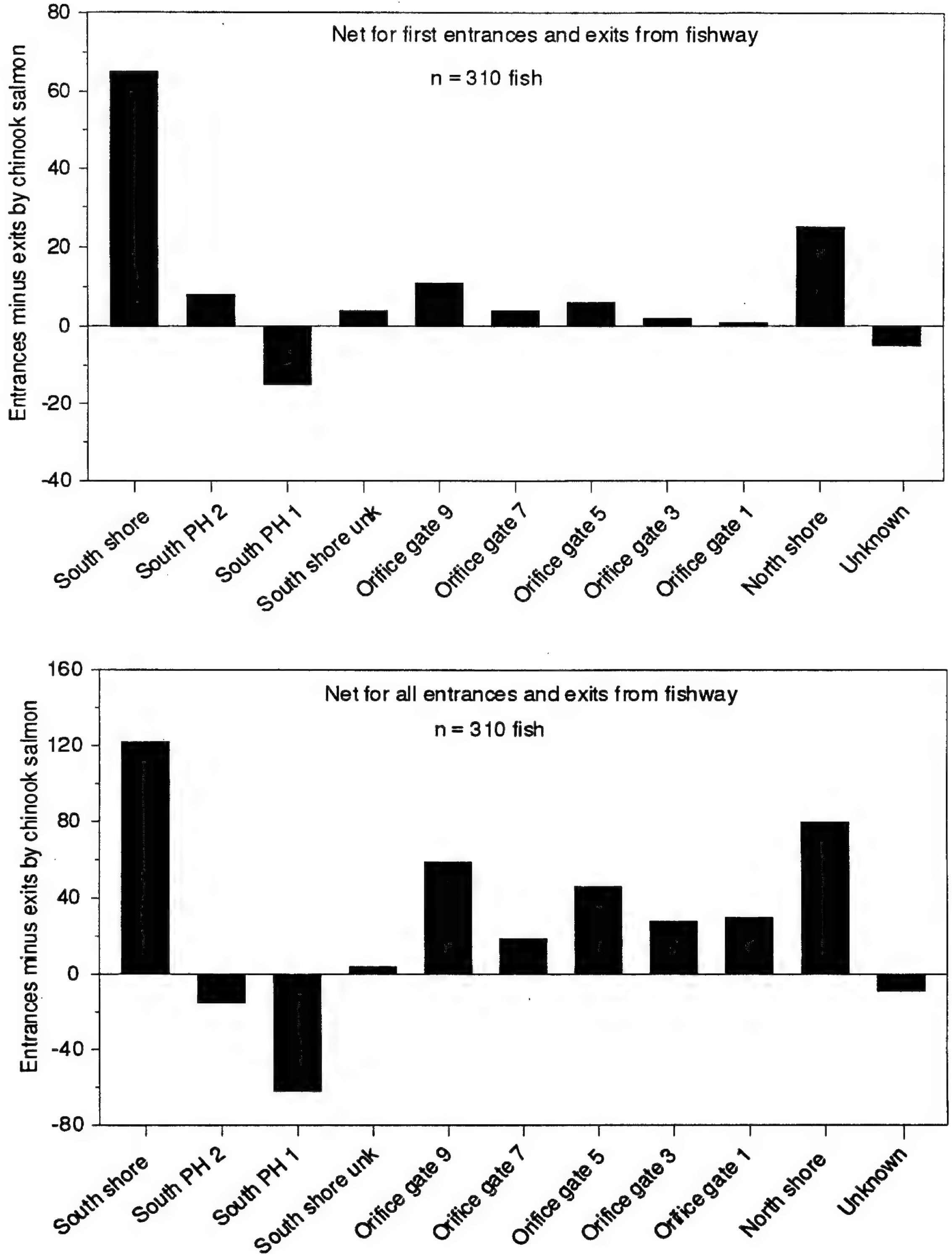


Figure 32. Net number of first and total entries and exits from fishway for each entrance by chinook salmon at Lower Monumental Dam in spring and early summer 1993.

Little Goose Dam

Fishway entrance use and movements within the fishway at Little Goose Dam were monitored in the spring and early summer of 1993 by recording movements of 306 chinook salmon with transmitters using the new digital spectrum processors connected to radio receivers. Antennas were placed near each entrance to the fishway, within the fishway, and at the top of the ladder (Figure 33). Median times for passage from the tailrace receiver (about 1 km downstream from the dam) at Little Goose Dam to the first recorded approach at an entrance, first entry into the fishway, and exit from the top of the ladder were 0.03, 0.16, and 0.7 d, respectively (Figure 34). The time between passage at the tailrace receiver and first entry into the fishway was about four hours (based on median passage times, Figure 34). Since 1993 was the first year we were able to collect reliable time of passage information on a large number of fish, we do not know if four hours median time to enter a fishway after first approach is normal, and an acceptable rate of passage .

The distribution of passage times were skewed to the right with a few fish taking several days to approach the entrances, enter the fishway, or pass over the dam (Figure 34). Mean passage times were longer than median times. Most of the fish entered the fishway within 6 hours after passing the tailrace receiver, but several fish took up to 3 d to pass the dam because they spent a day or more in the fishway or time exiting and re-entering the fishway. Some of the time spent in the fishway was at night when the fish temporarily discontinued their upstream migration, but some of the time was spent by fish migrating up and down the powerhouse collection channel during daylight (Figure 35). The passage time between the tailrace and the top of the ladder also includes the time some fish used when they exited the fishway via one of the entrances, moved out into the tailrace, and then re-entered the fishway.

Chinook salmon had a tendency to approach the dam first at either the south shore, NPE-1 or north shore entrances, although 29 of the 305 fish recorded approached orifice gate-1 first (Figure 36). The first approaches at NPE-1 and the north shore entrance is an indication that significant numbers of fish move up to the dam north of the powerhouse, perhaps circle through the spillway stilling basin, and pass by the north powerhouse entrances before entering the fishway.

When all the approaches at fishway entrances made by chinook salmon in the spring and early summer of 1993 are considered, chinook salmon concentrated along the powerhouse from NPE-1 to the south shore entrances (except OG-4) (Figure 36). The large number of approaches to entrances (35 per fish on average, 10,700 total) is an indication that chinook salmon were somewhat hesitant to enter the fishway and moved back and forth along the dam before entering the fishway. About 37% of the 306 chinook salmon monitored, had approached the dam 10 or fewer times, but several fish approached various entrances 40 or more times (Figure 37).

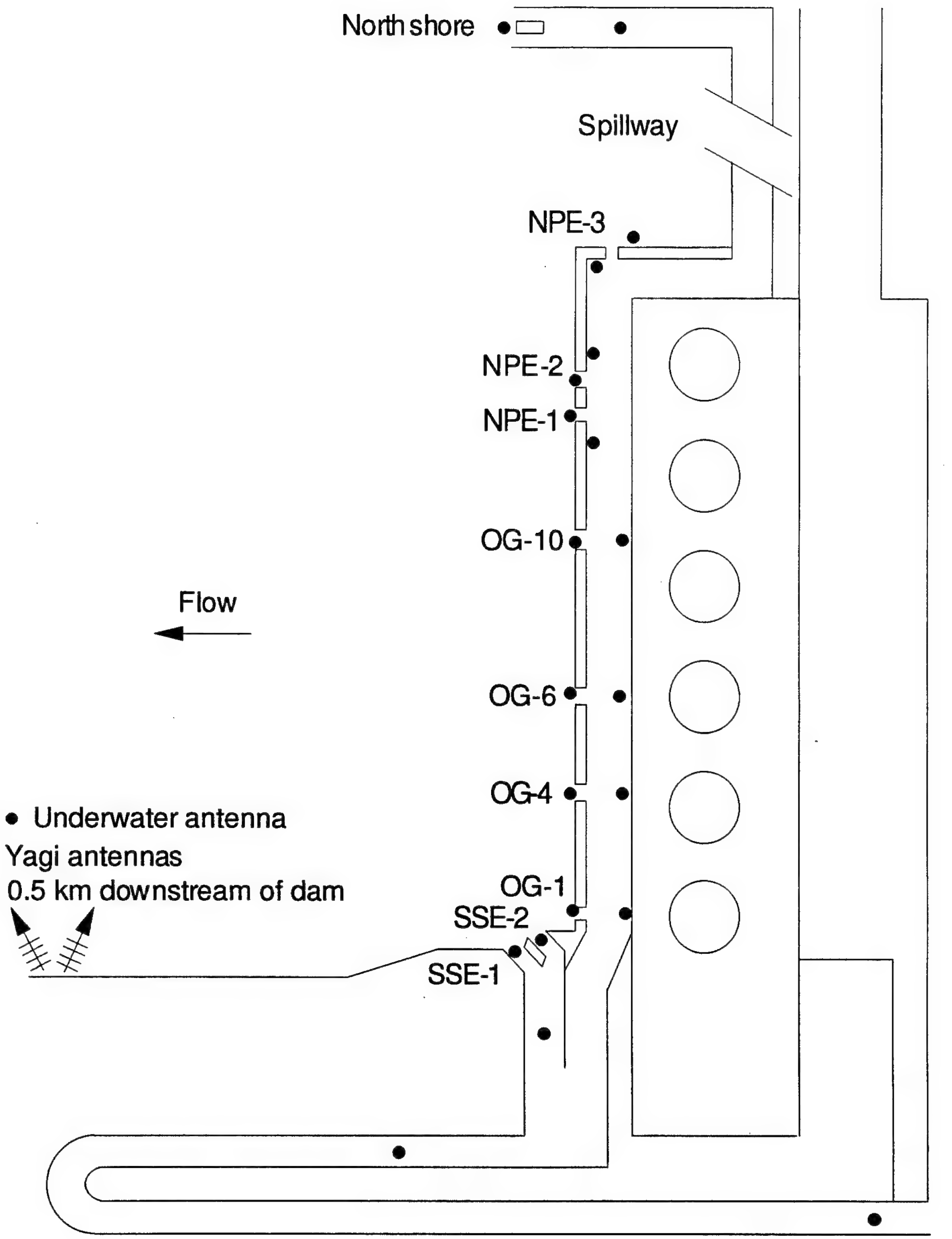


Figure 33. Location of antennas at Little Goose Dam in 1993 during the spring and early summer when chinook salmon were passing the dam.

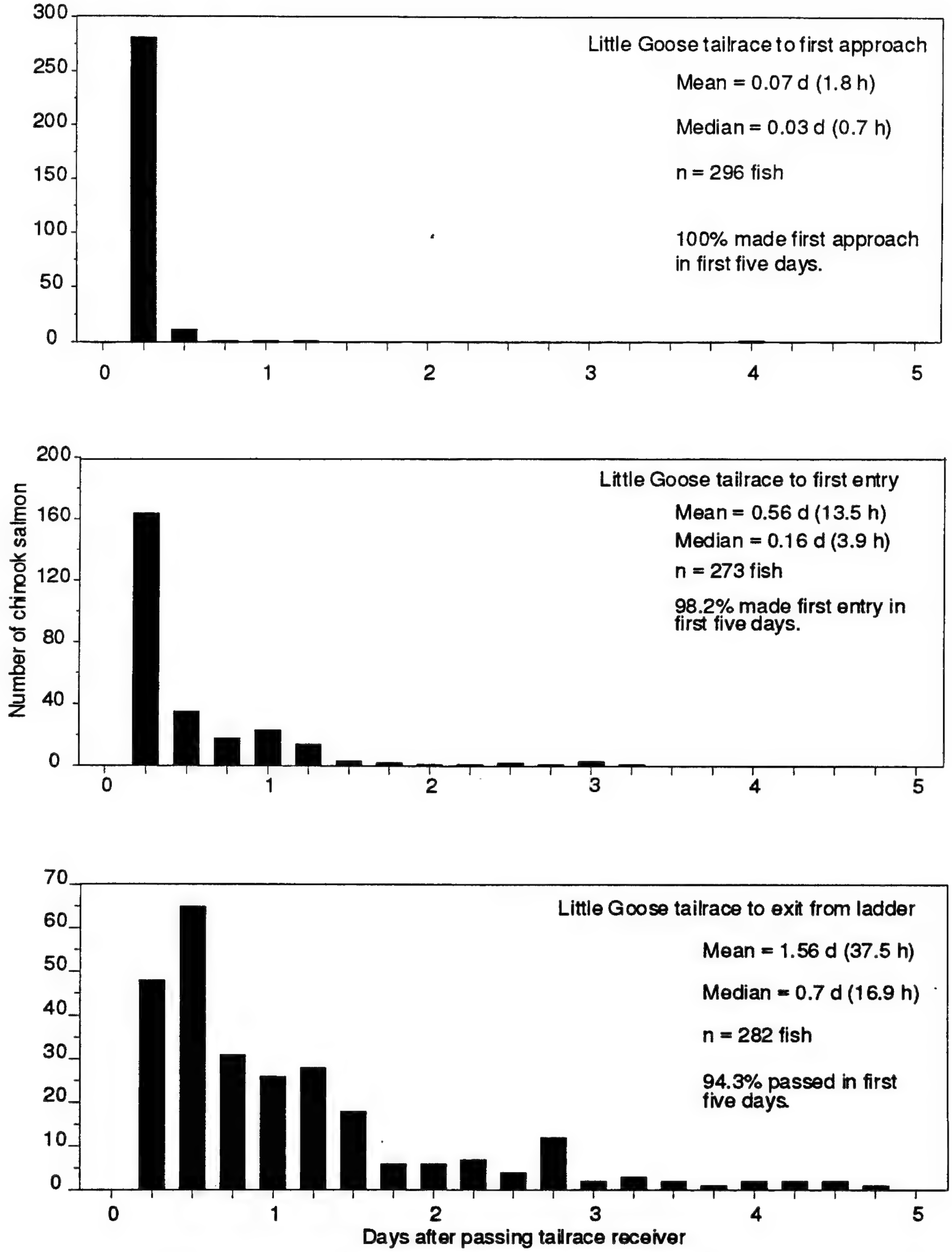


Figure 34. Distribution of numbers of chinook salmon and days to pass from the Little Goose Dam tailrace to first approach at a fishway entrance, first entry into the fishway, and exit from the top of the ladder in spring and early summer 1993.

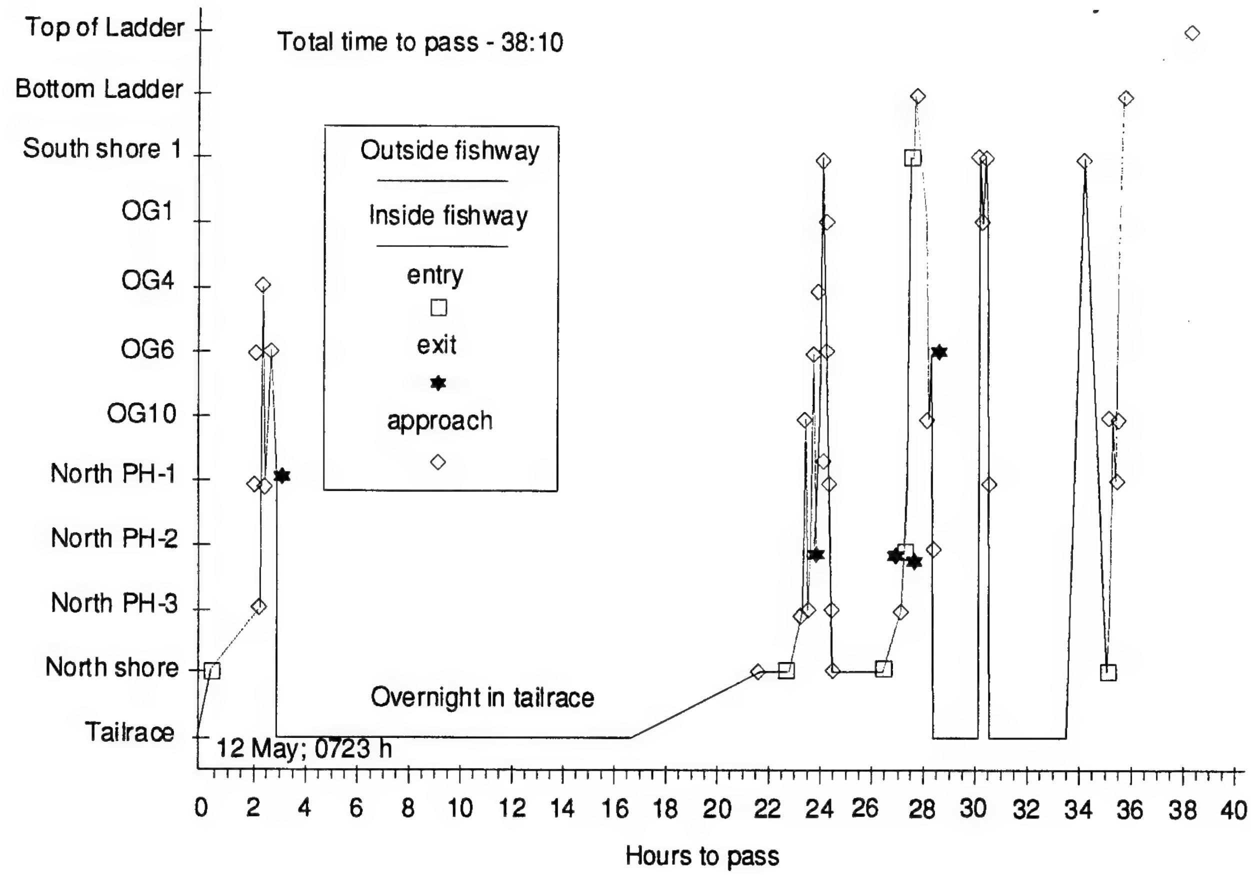


Figure 35. Diagram of Little Goose Dam with an illustration of the types of movements made be some chinook salmon in the spring and early summer 1993 when approaching the dam and passing through the fishway.

The entrances to the fishway used by chinook salmon in the spring and early summer of 1993 were more restricted than the entrances approached. For example, a majority of the first and repeated entries into the fishway occurred at the south and north shore entrances (Figure 38), whereas many of the approaches to the fishway were at the floating orifice-gate entrances (except OG-4) and NPE-1 (Figure 36). Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those openings. The location of discharges from the dam was an important factor in where fish approached the dam, but not the only factor as illustrated by the higher than average numbers of fish that approached the dam and entered the fishway at the NPE-1 and north shore entrances where there was no flow (except during spill) to attract the fish other than that coming from the fishway. The relatively low use of the orifice-gate entrances may have resulted because discharges (design of 60 cfs) from those entrances mixed with the discharges from the turbines, the discharge was not attractive to the fish (volume and velocity), and the size and depth of the orifice-gate openings may not have been as attractive as other openings. The orifice gate entrances at Little Goose Dam are 2 feet high and 6 feet wide, with the top of the opening 4 feet down from the water surface. South shore entrance is comprised of two 4-foot-wide vertical weir gates and the north shore entrance is made up of two 6-foot-wide vertical weir gates. Weir gates at both entrances are adjustable for tailrace conditions but are generally set to an 8 foot water depth.

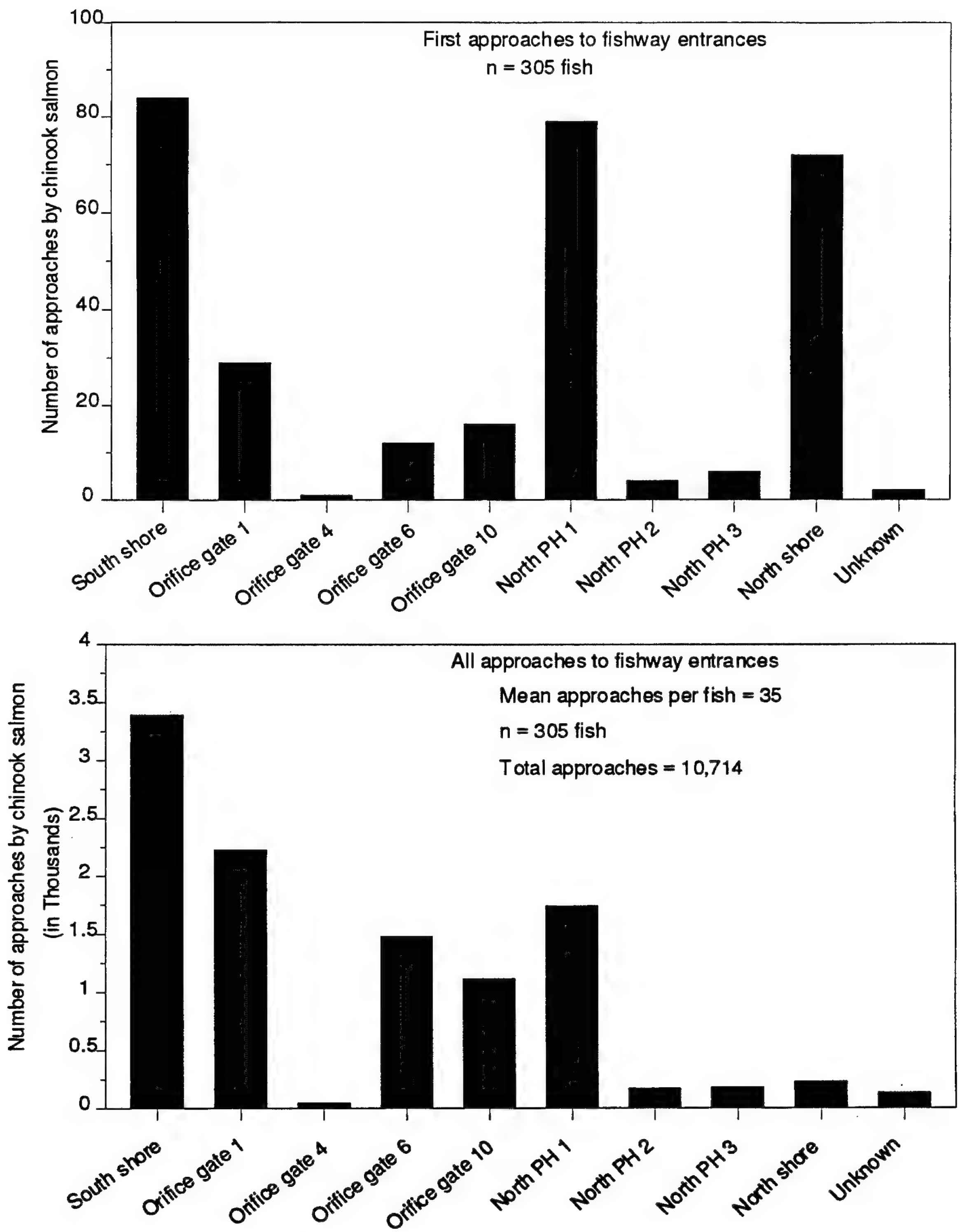


Figure 36. Number of first and total approaches at fishway entrances at Little Goose Dam by chinook salmon in the spring and early summer 1993.

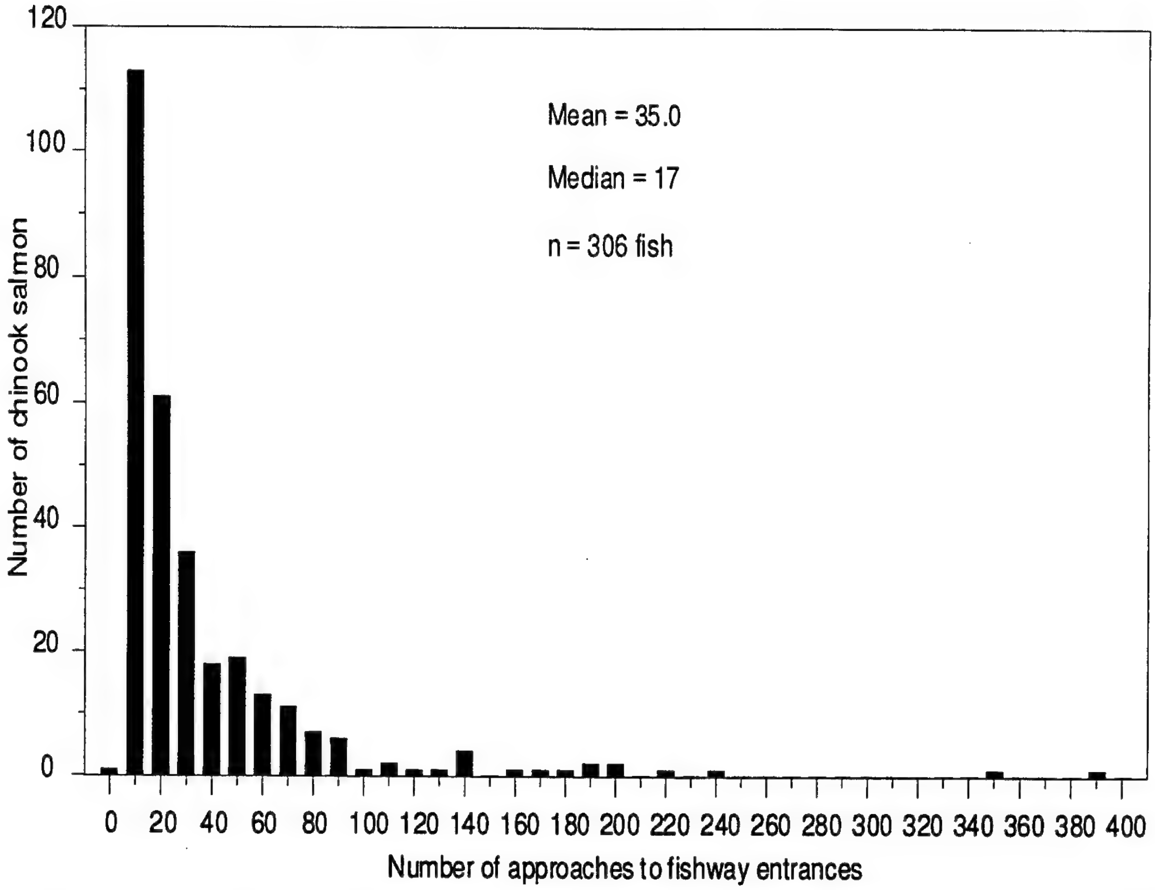


Figure 37. Number of chinook salmon approaching fishway entrances one or more times at Little Goose Dam in spring and early summer 1993.

Many chinook salmon (127 of 306 monitored, 42%) entered the fishway at Little Goose Dam only once (Figure 39). About 60% of the fish entered two or more times. About 40% of the chinook salmon that entered the fishway did not exit the fishway through any of the entrances, and the remainder exited the fishway 1 to 21 times.

Chinook salmon exited from the fishway via all of the entrances, but more did so at the south shore and NPE-1 and -2 entrances (Figure 40). The number of fish exiting from the fishway at the NPE-1 and -2 entrances was probably increased by the fishway fence that was installed to reduce the number of fish that left the fishway via the NPE-1 and -2 entrances. A high exit rate had been observed at the north powerhouse entrances (Turner et al. 1982; 1983) and the fence was installed to guide fish migrating upstream in the collection channel past the two entrances. From the 1992 studies, we found that many fish moved downstream in the collection channel and if they moved as far as the north end of the powerhouse and were on the tailrace side of the channel, the fence would guide them to the north powerhouse entrance, just the opposite of the intended purpose of the fence.

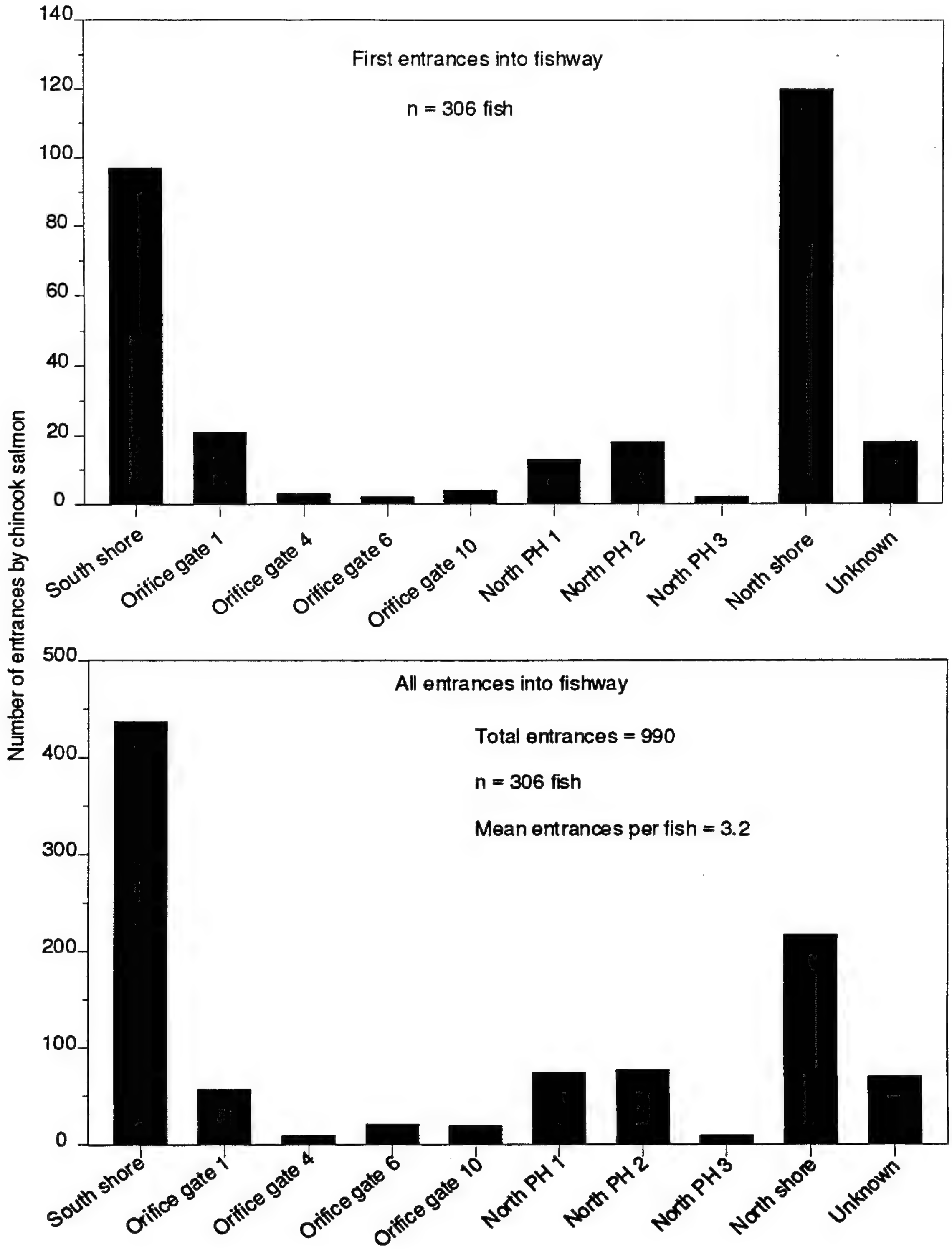
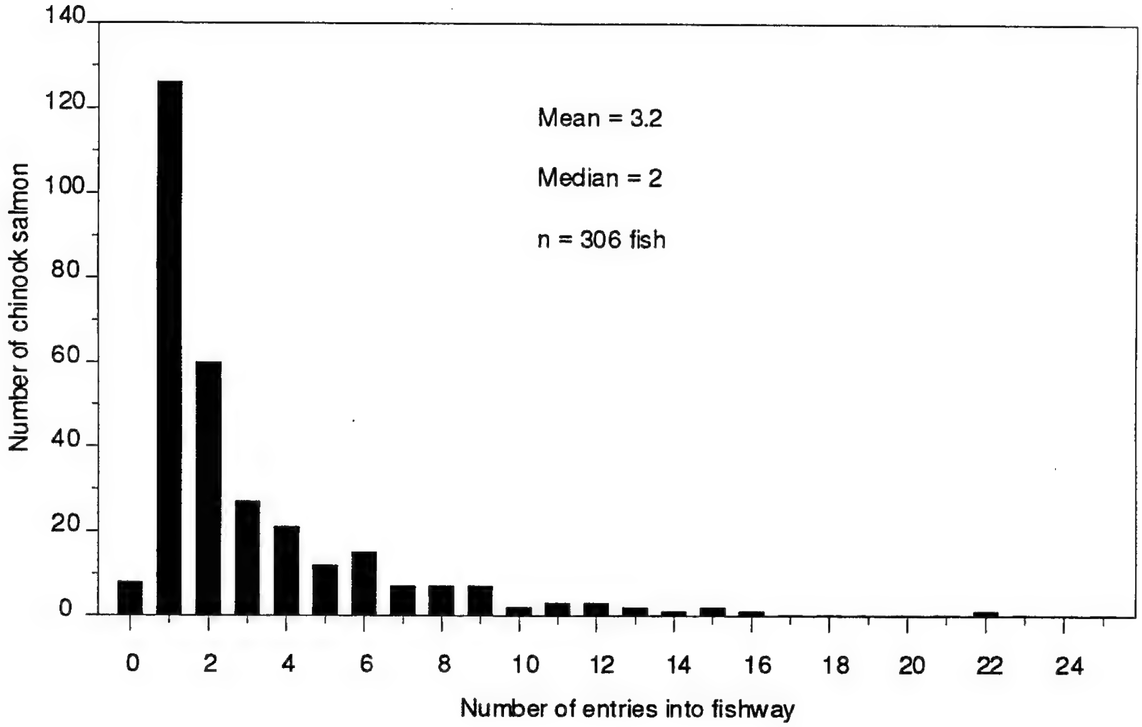


Figure 38. Number of first and total entries by chinook salmon into the Little Goose Dam fishway via each entrance in spring and early summer 1993.



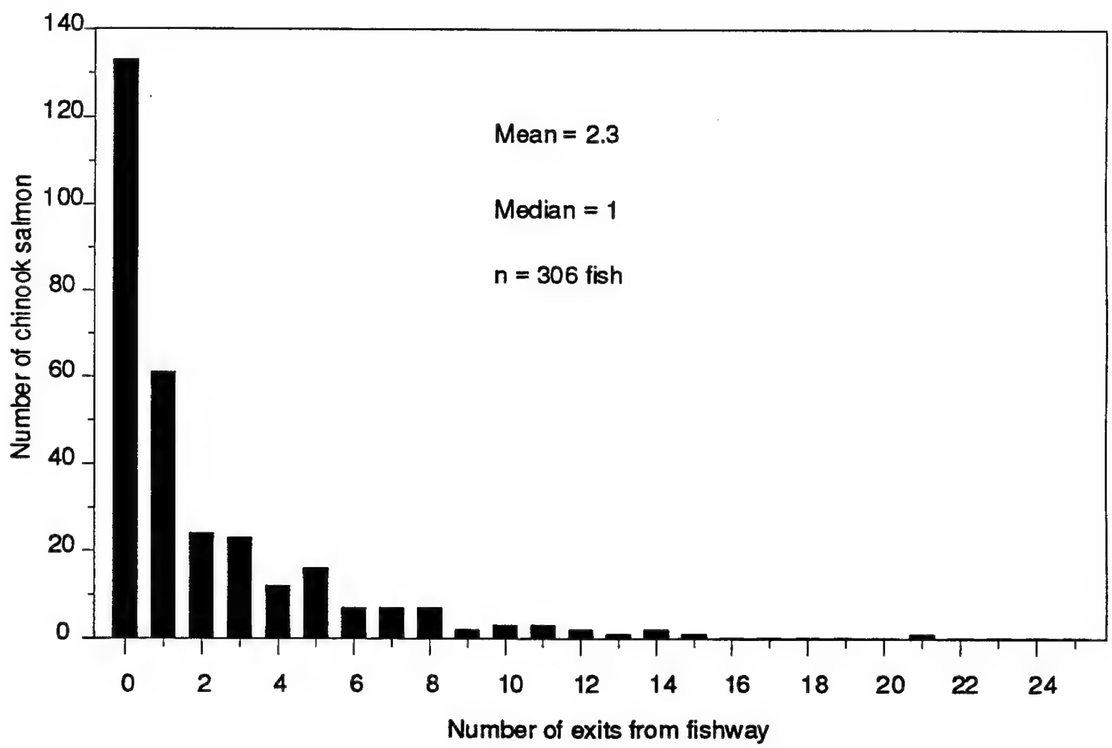


Figure 39. Number of chinook salmon that did not enter or exit, and those with multiple entries and exits into or from the fishway at Little Goose Dam via the entrances in spring and early summer 1993.

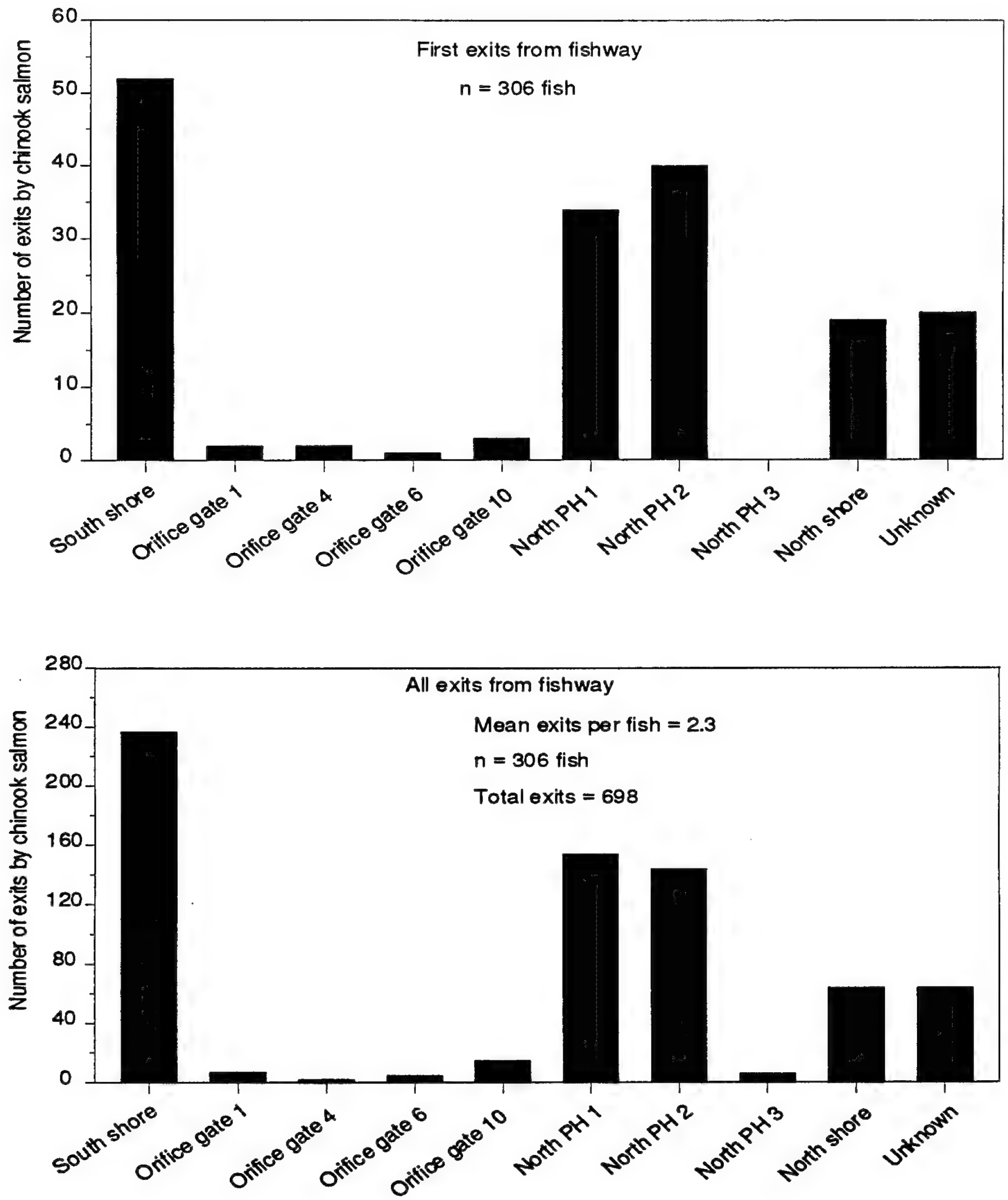
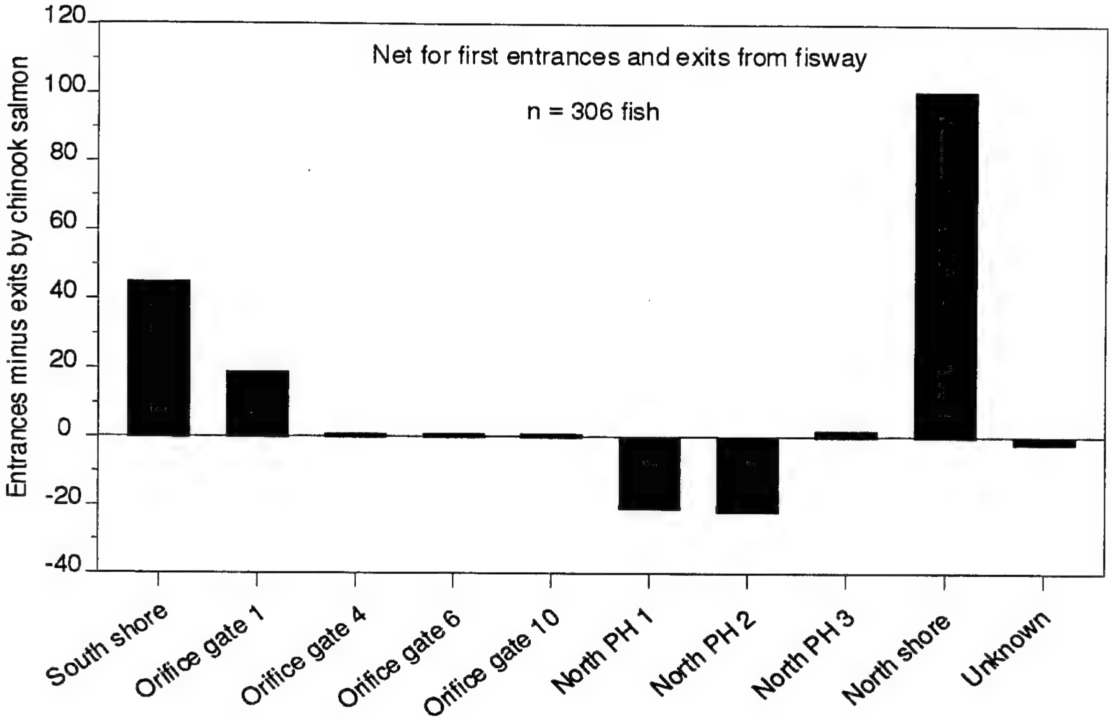


Figure 40. Number of first and total exits from fishway for each entrance by chinook salmon at Little Goose Dam in spring and early summer 1993.

Net entry rates (entrances minus exits) for the fishway entrances ranged from about 100 to -20 for first entries and exits, and 200 to -75 for all entries and exits (Figure 41). Overall the south shore entrance was the most effective entrance followed by northshore and orifice gate 1. There were more exits than entries of chinook salmon at the NPE-1 and -2 entrances. Entries exceeded exits at OG-4, -6, -10, and NPE-3.



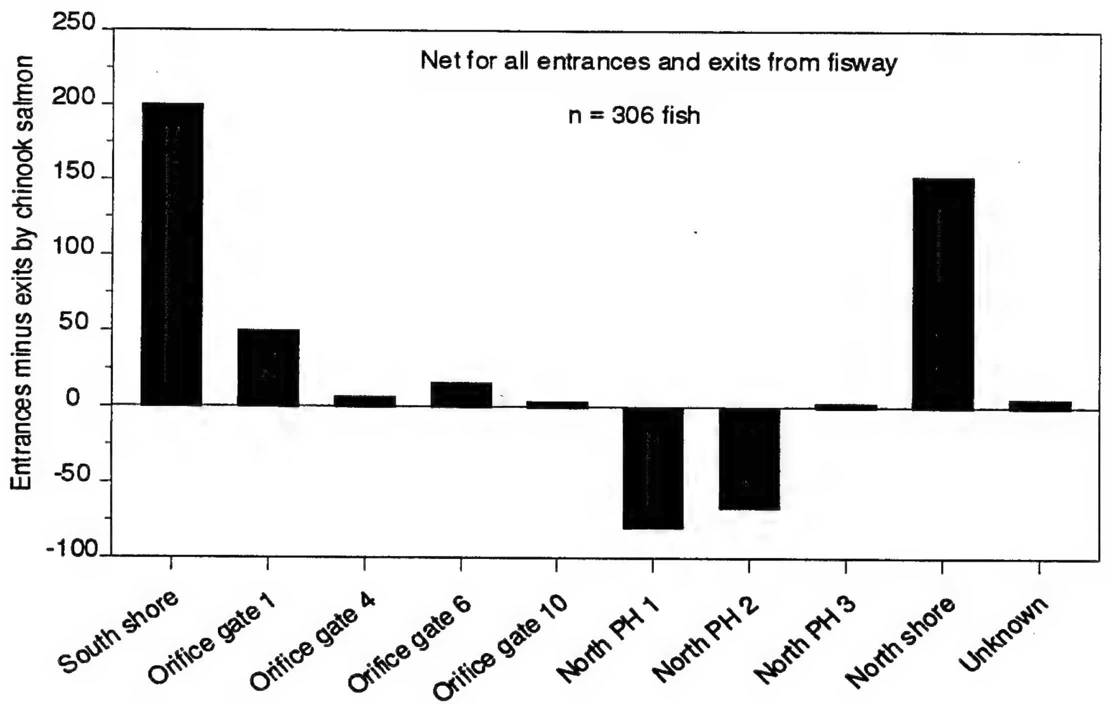


Figure 41. Net number of first and total exits from fishway for each entrance by chinook salmon at Little Goose Dam in spring and early summer 1993.

Lower Granite Dam

Fishway entrance use and movements within the fishway at Lower Granite Dam were monitored in the spring and early summer of 1993 by recording movements of 321 chinook salmon with transmitters using the digital spectrum processors (DSP) connected to radio receivers (SRX400). Antennas were placed near each entrance to the fishway, within the fishway, and at the top of the ladder (Figure 42).

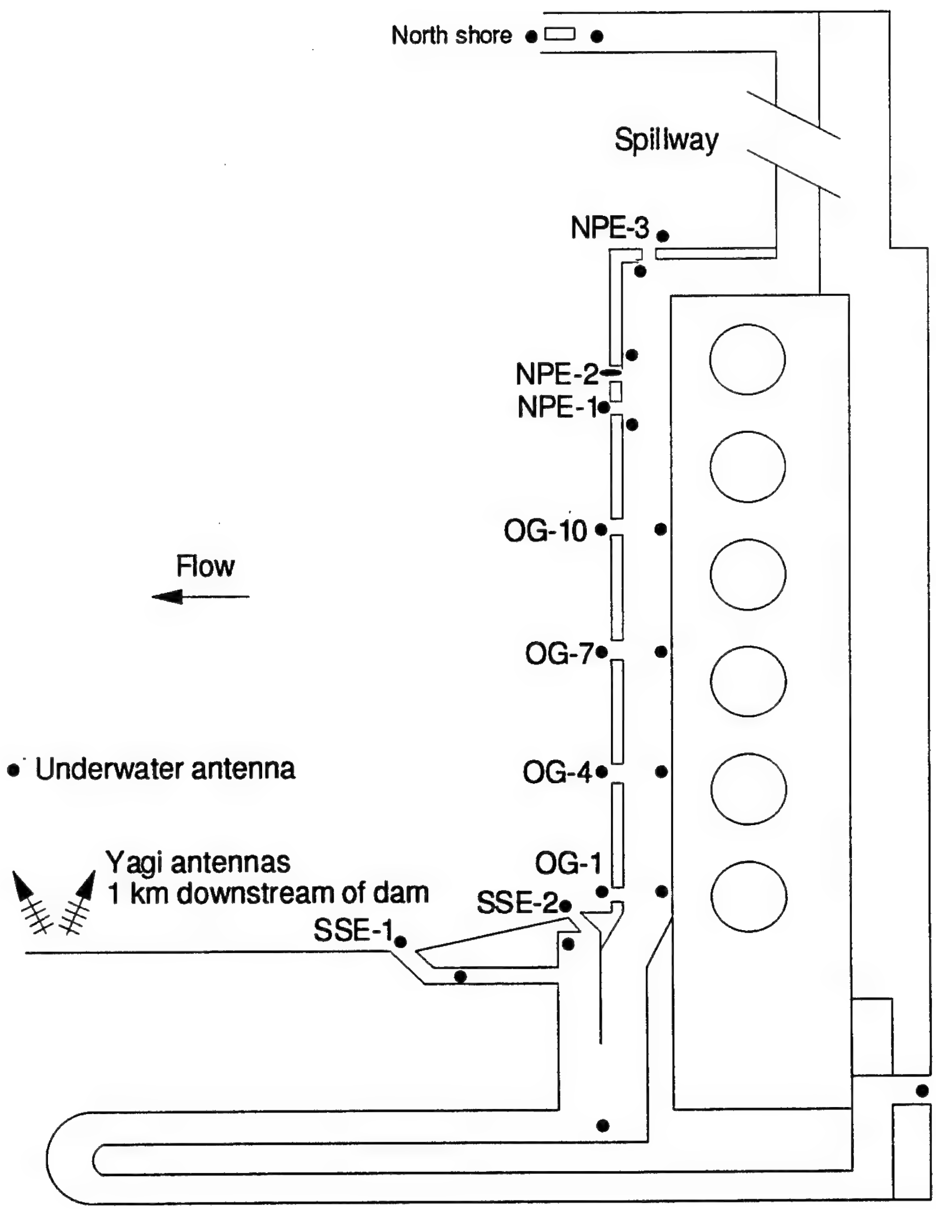


Figure 42. Location of entrances to fishway and antennas at Lower Granite Dam in 1993 during the spring and early summer when chinook salmon were passing the dam.

Median times for passage from the tailrace receiver (about 1 km downstream from the dam) at Lower Granite Dam to the first recorded approach at an entrance, first entry into the fishway, and exit from the top of the ladder were 0.03, 0.08, and 0.76 d, respectively (Figure 43). The median time of 1.9 hours to pass from the tailrace receiver to first entry into the fishway at Lower Granite Dam was the fastest rate observed at the four dams. Since 1993 was the first year we were able to collect reliable time of passage information on a large number of chinook salmon, we do not know if two hours median time to enter a fishway after passing into the tailrace is normal and acceptable.

The distribution of passage times were skewed to the right with a few fish taking several days to enter the fishway or pass over the dam (Figure 43). Mean passage times were longer than median times. Most of the fish entered the fishway within 6-12 hours after passing the tailrace receiver, but several fish took up to 3 d to pass the dam because they spent a day or more in the fishway or time exiting and re-entering the fishway. Some of the time spent in the fishway was at night when the fish temporarily discontinued their upstream migration, but some of the time was spent by fish migrating up and down the powerhouse collection channel during daylight (Figure 44). The passage time between the tailrace and the top of the ladder also includes some fish that exited the fishway via one of the entrances, moved out into the tailrace, and then re-entered the fishway.

Chinook salmon had a tendency to approach the dam first at NPE-2, SSE-1 and OG-10 (Figure 45). The first approaches at NPE-2 is an indication that significant numbers of fish move up to the dam north of the powerhouse, perhaps circle through the spillway stilling basin, and pass by the NPE-2 entrance before entering the fishway. Of 321 first approaches recorded at Lower Granite Dam, 105 occurred at NPE-2. When there was spill, the fish probably followed the south edge of the spill flow which would have led them to the north end of the powerhouse and NPE-2.

When all the approaches at fishway entrances made by chinook salmon in the spring and early summer of 1993 are considered, fish approached the fishway at all entrances several times except at OG-4, NPE-3, and the north shore entrance (Figure 45). The large number of approaches to entrances (52 per fish on average, 16,832 total) is an indication that chinook salmon were somewhat hesitant to enter the fishway and moved back and forth along the dam several times before entering the fishway. About 29% of the 321 chinook salmon monitored, had approached the dam 10 or fewer times, but several fish approached various entrances 50 or more times (Figure 46). Although chinook salmon moved back and forth along the dam and approached the entrances several times, the median time between first approach and first entry into the fishway was only about 1.2 hours (median time to first entry minus median time to first approach, Figure 43). Time from first approach to first entry at the other three dams ranged from 1.4 to 3.2 hours in 1993.

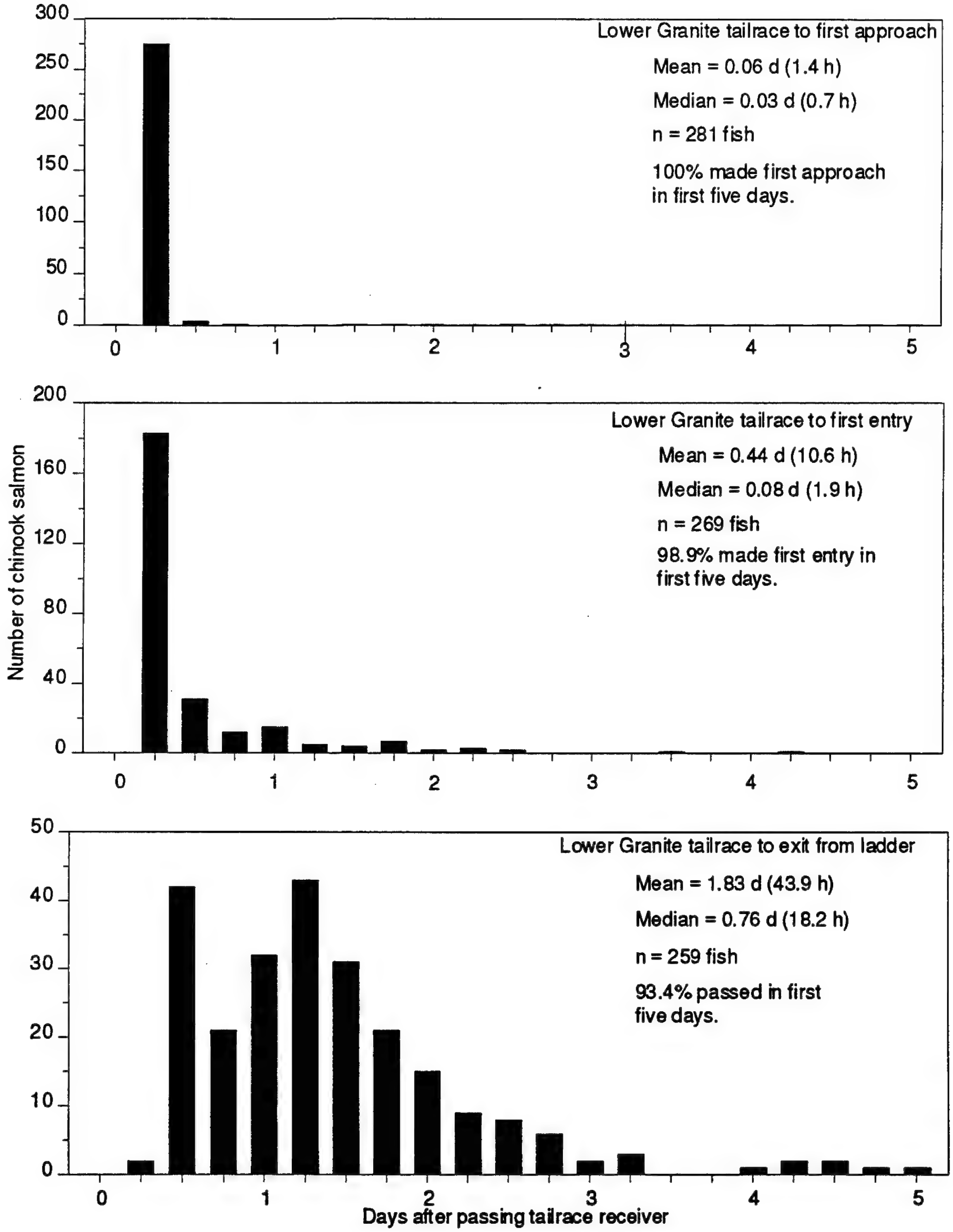


Figure 43. Distribution of numbers of chinook salmon and days to pass from the Lower Granite Dam tailrace to first approach at a fishway entrance, first entry into the fishway, and exit from the top of the ladder in spring and early summer 1993.

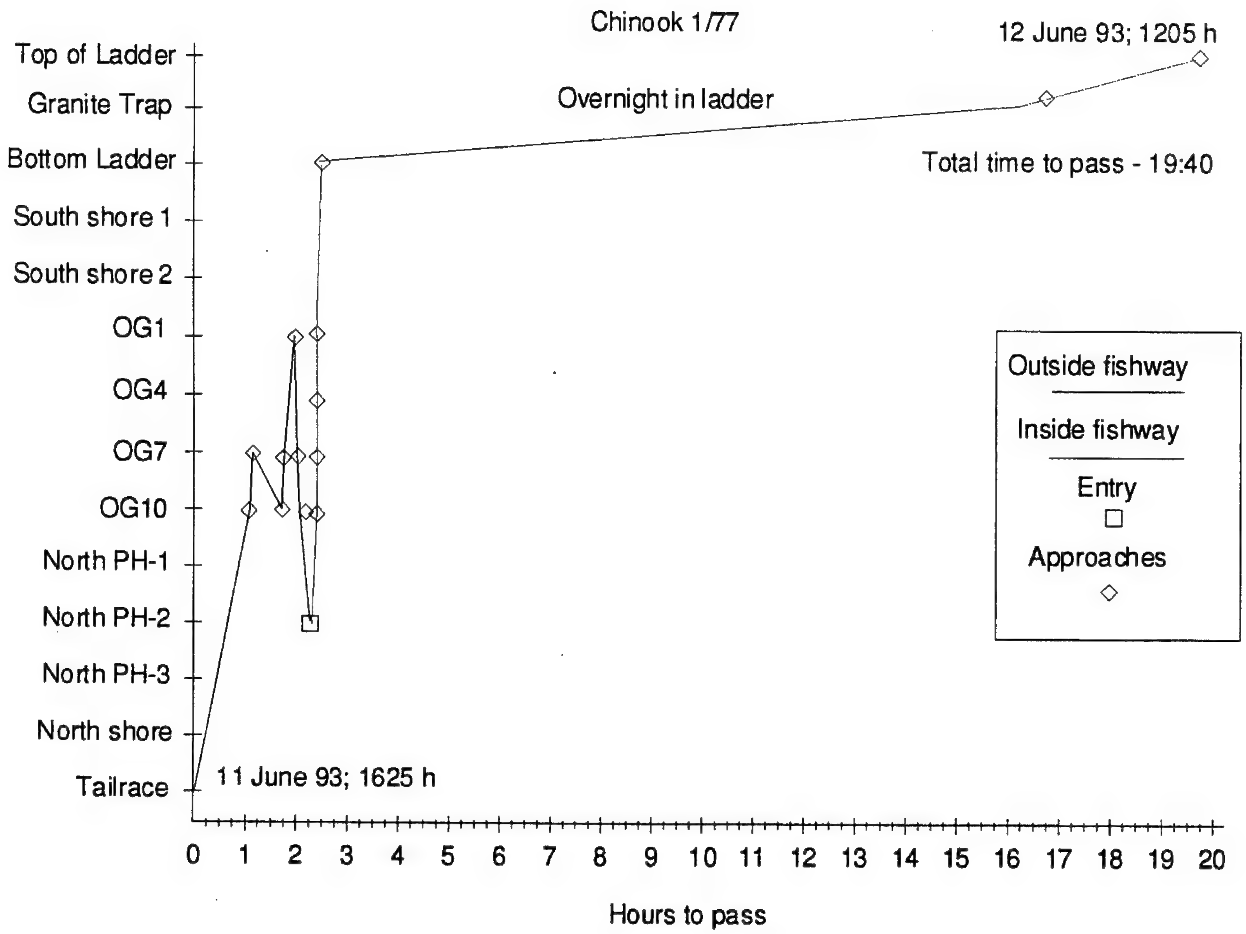


Figure 44. Diagram of the types of movements made by some chinook salmon in the spring and early summer of 1993 when approaching Lower Granite Dam and passing through the fishway.

The entrances to the fishway used by chinook salmon in the spring and early summer 1993 were more limited than the entrances approached. For example, a majority of the first and repeated entries into the fishway occurred at the SSE-1, NPE-1 and -2, and north shore entrances (Figure 47), whereas many of the approaches to the fishway were at the floating orifice-gate entrances in addition to the most used entrances (Figure 45). Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those openings. The location of discharges from the dam was an important factor in where fish approached the dam, but not the only factor as illustrated by the higher than average numbers of fish that approached the dam and entered the fishway at NPE-1 and -2, and north shore entrances where there was no flow (except during the limited period of spill) to attract the fish other than that coming from the fishway. The relatively low use of the orifice-gate entrances may have resulted because discharges (design of 60 cfs) from those entrances mixed with the discharges from the turbines and was not attractive to the fish (volume and velocity), and the size

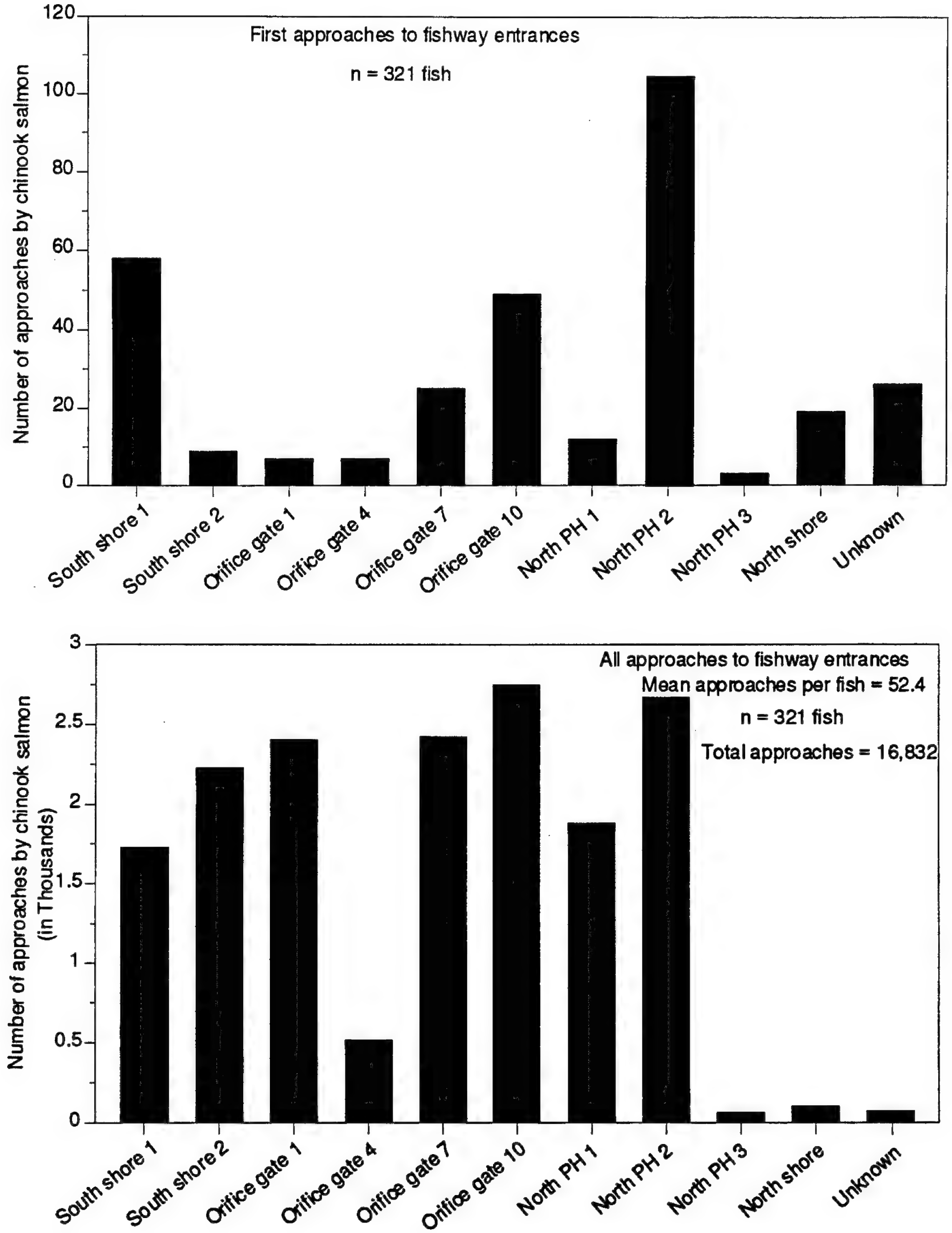


Figure 45. Number of first and total approaches at fishway entrances at Lower Granite Dam by chinook salmon in the spring and early summer of 1993.

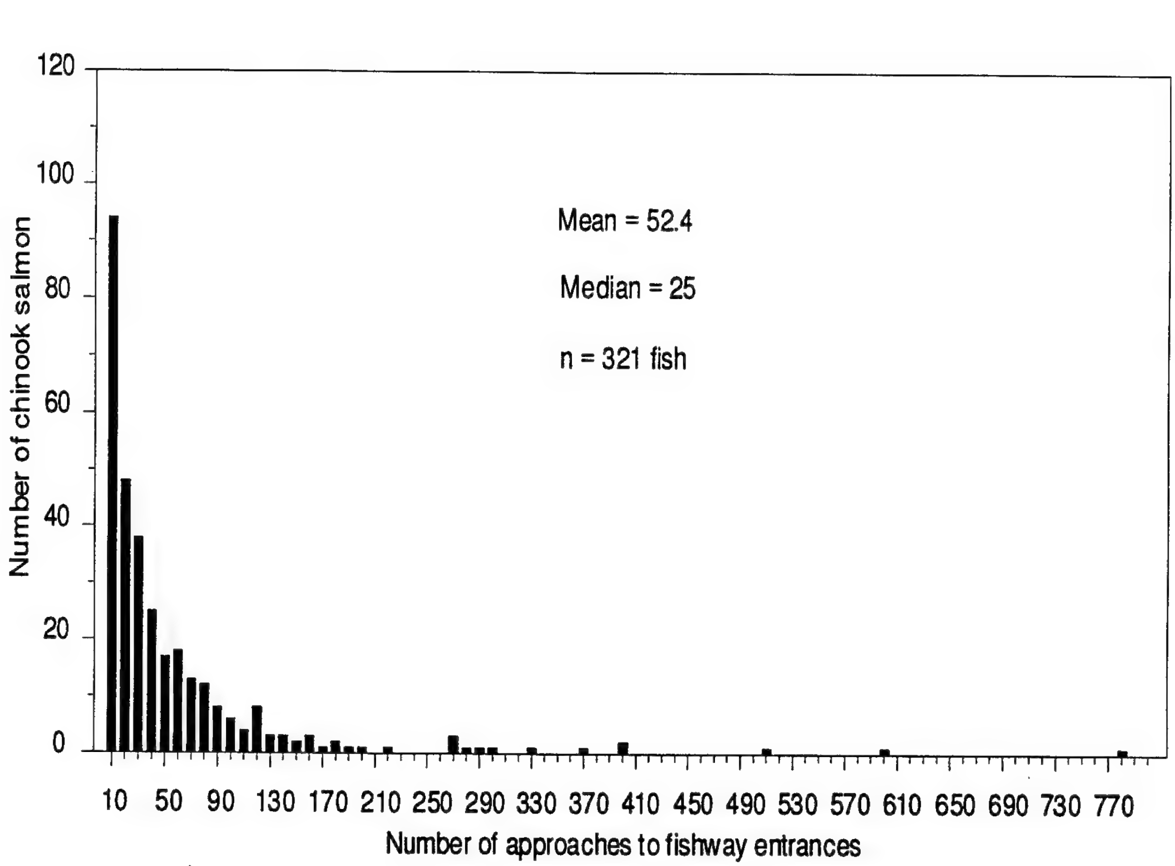


Figure 46. Number of chinook salmon approaching fishway entrances one or more times at Lower Granite Dam in the spring and early summer 1993.

and depth of the orifice-gate openings may not have been as attractive as other openings. The orifice gate entrances at Lower Granite Dam are 2 feet high and 6 feet wide, with the top of the opening 4 feet down from the water surface. South shore entrance-2 is a 4 foot wide vertical slot with an 8 foot water depth.

Many chinook salmon (119 of 321 monitored, 37%) entered the fishway at Lower Granite Dam only once (Figure 48). About 60% of the fish entered two or more times. About 37% of the chinook salmon that entered the fishway did not exit the fishway through any of the entrances, and the remainder exited the fishway 1 to 25 times.

Chinook salmon exited from the fishway via all of the entrances, but more did so at the NPE-1 and -2, SSE-1 and -2, and north shore entrances (Figure 49). The fishway fence that was installed to reduce the number of fish leaving the fishway via the NPE-1 and -2 entrances was removed in February 1993. A high exit rate had been observed at the north powerhouse entrances (Turner et al. 1982; 1983) and the fence was installed to guide fish migrating upstream in the collection channel past the two entrances. From the 1992 studies, we found that many fish moved downstream in the collection channel and

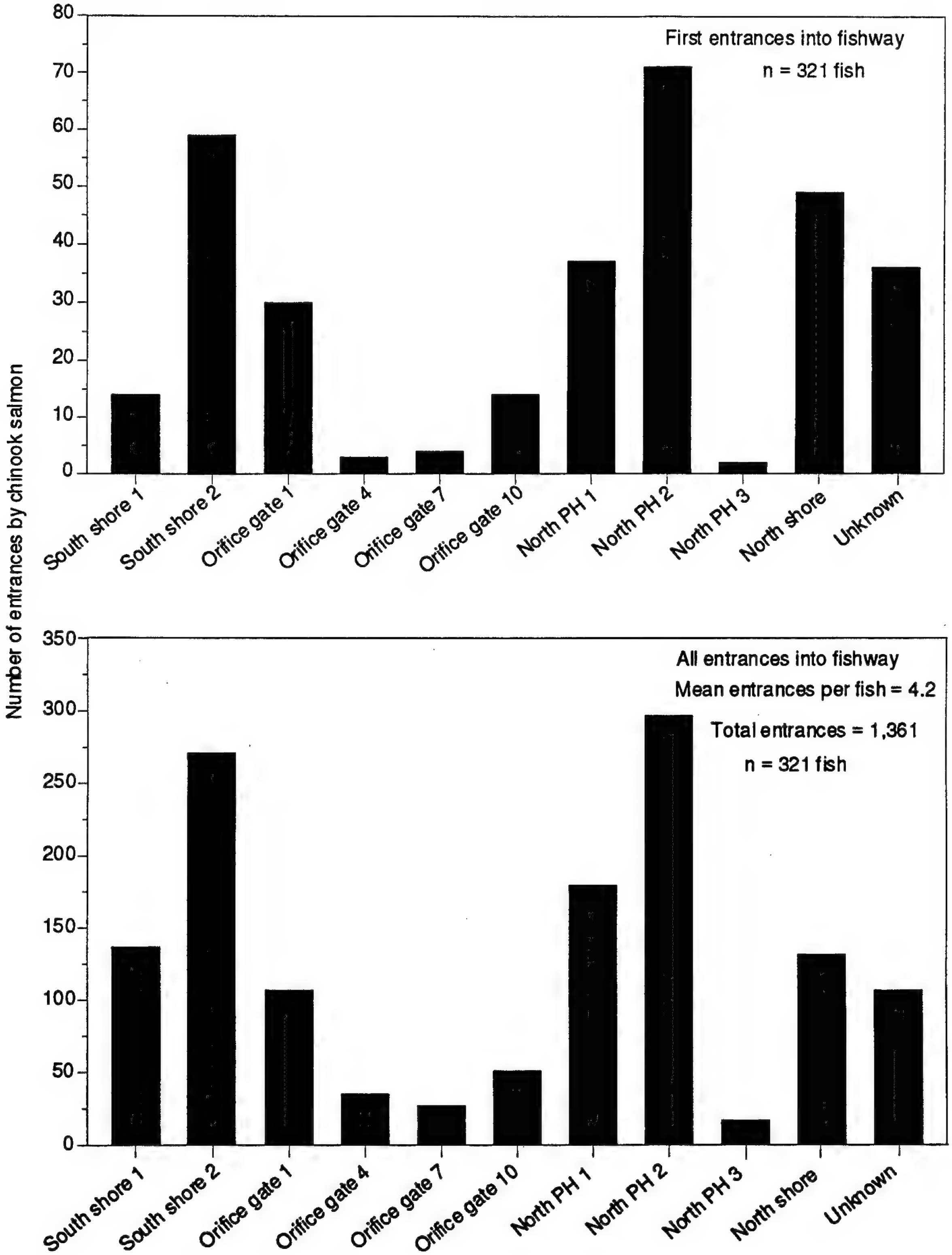
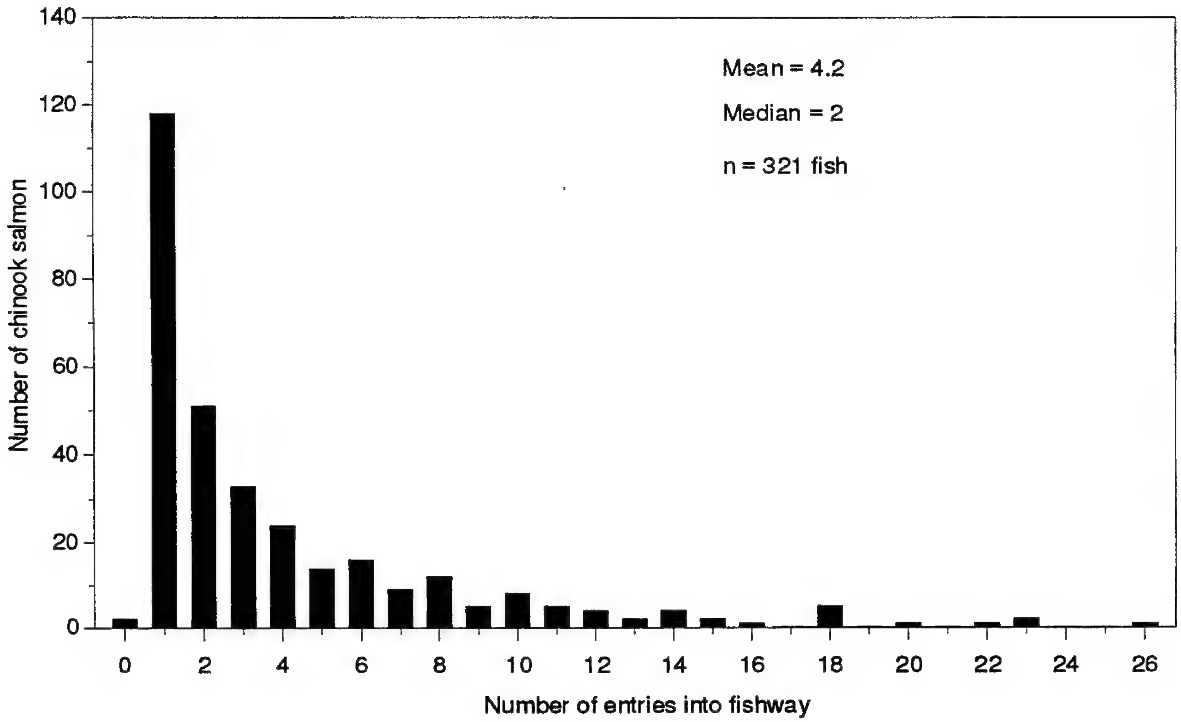


Figure 47. Number of first and total entries by chinook salmon into the Lower Granite Dam fishway via each entrance in spring and early summer 1993.



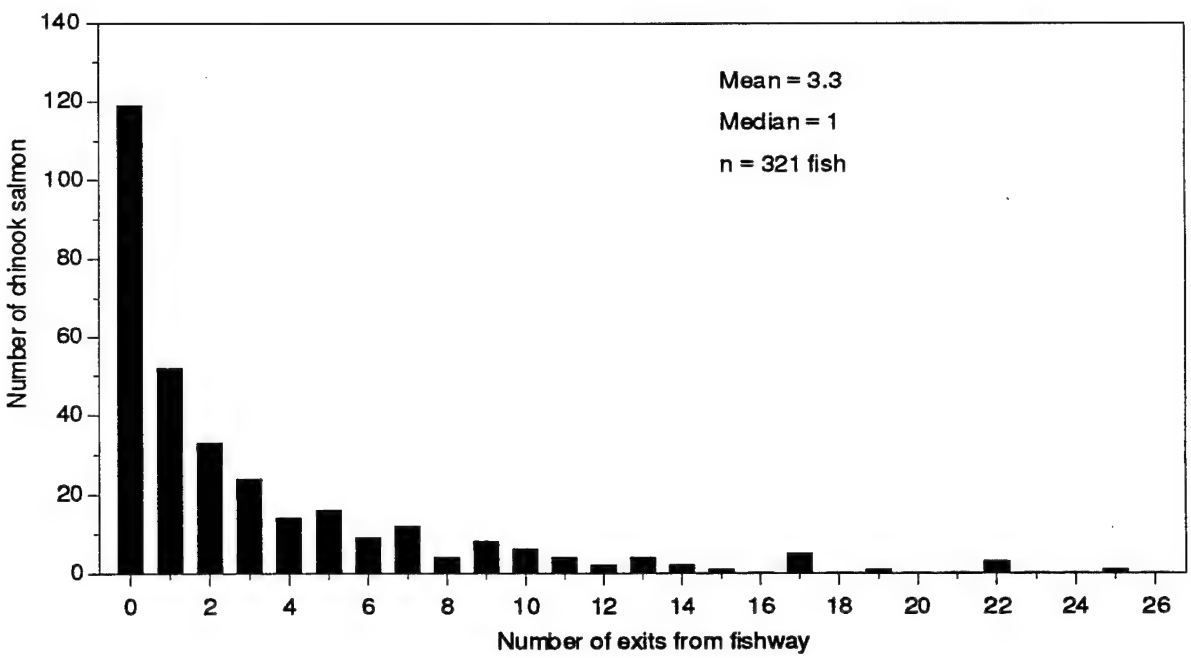
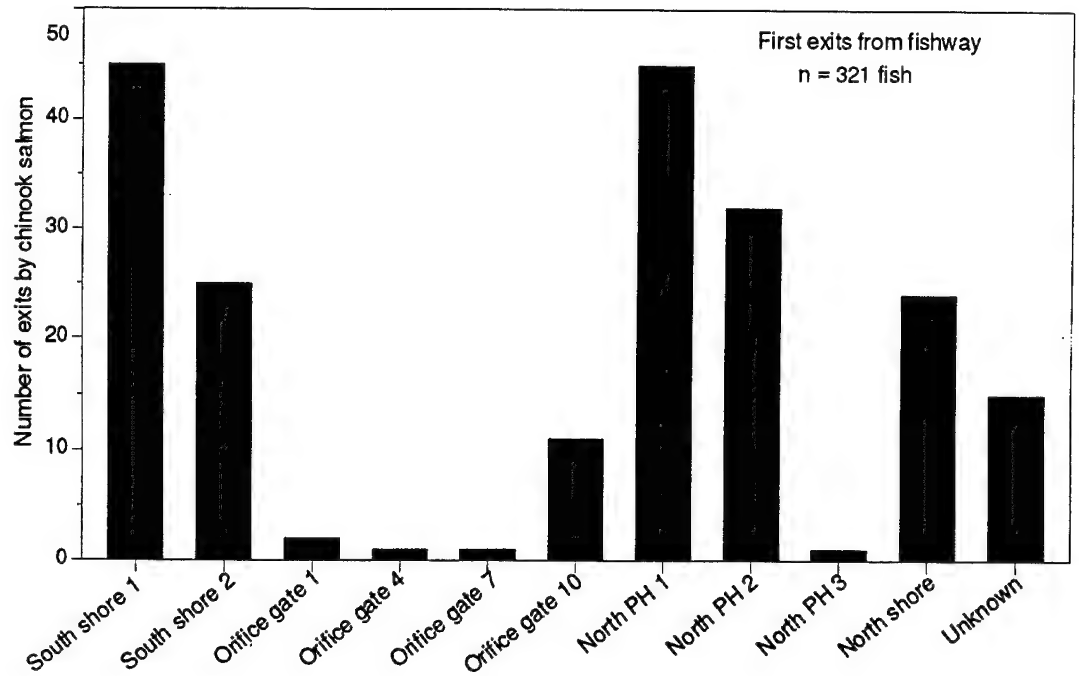


Figure 48. Number of chinook salmon that did not enter or exit, and those with multiple entries and exits into or from the fishway at Lower Granite Dam for all entrances combined in spring and early summer 1993.



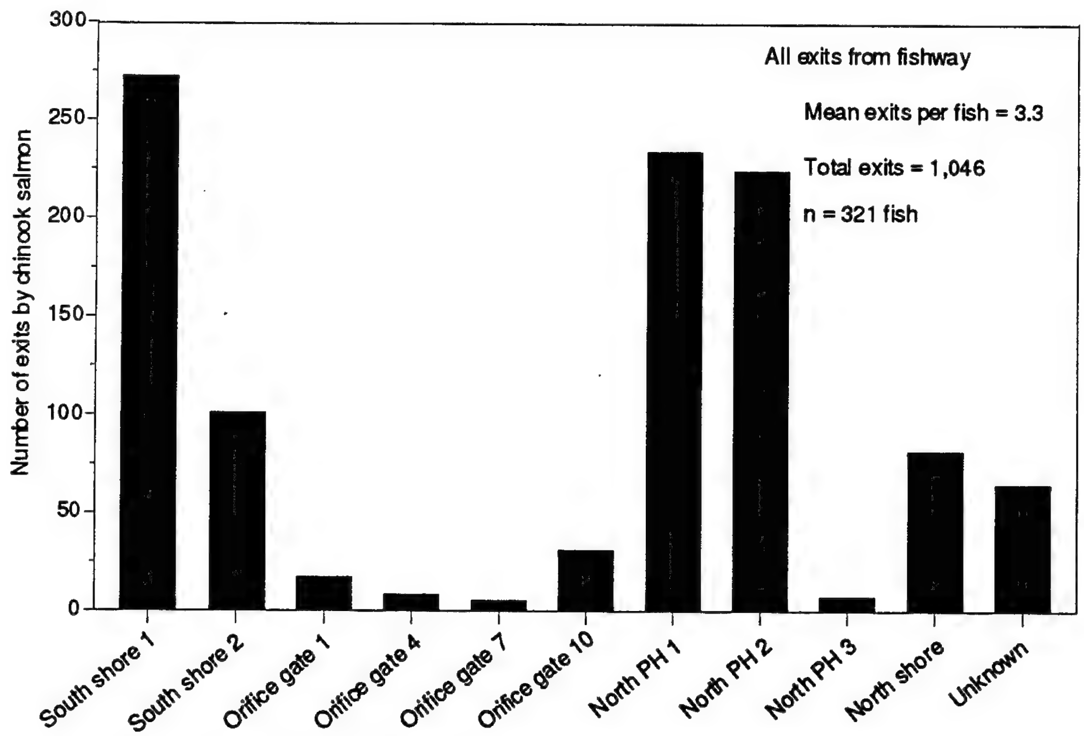


Figure 49. Number of first and total exits from the fishway for each entrance by chinook salmon at Lower Granite Dam in spring and early summer 1993.

if they moved as far as the north end of the powerhouse and were on the tailrace side of the channel, the fence would guide them to the north powerhouse entrance, just the opposite of the intended purpose of the fence. Net entry rates (entrances minus exits) for the fishway entrances ranged from about 40 to -30 for first entries and exits, and 170

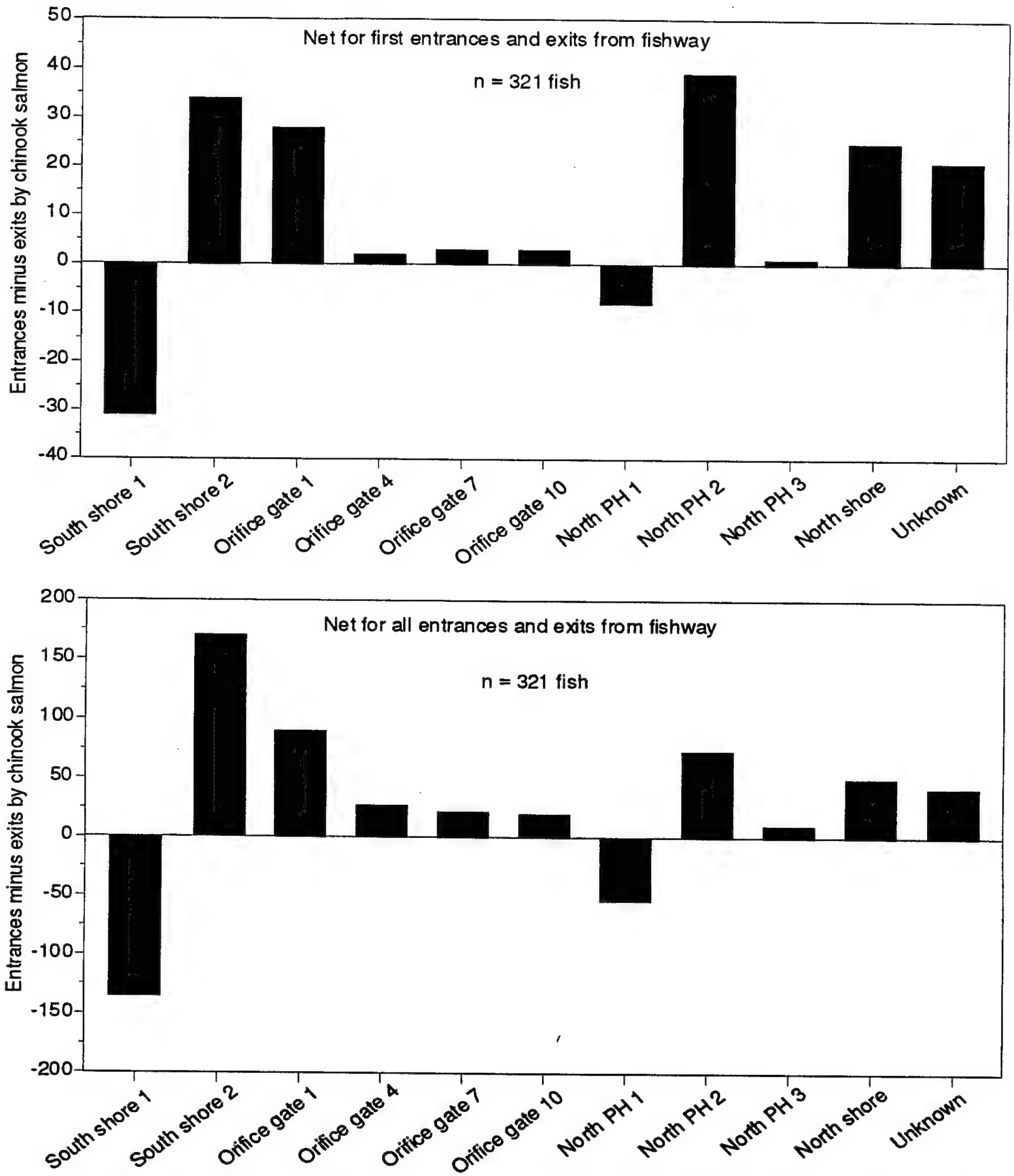


Figure 50. Net number of first and total entries and exits from the fishway for each entrance by chinook salmon at Lower Granite Dam in spring and early summer 1993.

to -130 for all entries and exits (Figure 50). For first entrances and exits, NPE-2 was the most efficient followed by SSE-2, OG-1, and the north shore entrance. For all entries and exits, SSE-2 was the most efficient followed by OG-1, NPE-2, and the north shore entrance. There were more exits than entries of chinook salmon at the SSE-1 and NPE-1 entrances. Entries exceeded exits at OG-4, -7, -10 and NPE-3.

Chinook Salmon - 1993 Spill Pattern Test

Methods

Snowmelt runoff and spring rains in 1993 provided sufficient river discharge to force spill and allowed us to conduct spill pattern tests during May and June at each of the lower Snake River dams. Length of the spill period and amount of water spilled varied at each of the dams based on the number of turbines in operation and river discharge. At Ice Harbor Dam continuous daytime spill occurred from 24 April to 29 June after which nighttime spill for juvenile passage continued (Figure 51). Turbine units 4 and 5 were off line from the beginning of the spill season to 5 May for unit 4 and until 10 May for unit 5, after which all units were in service through the end of May. Unit 5 was off line from 2 June through the end of the spill season and unit 4 was out of service beginning 25 June. At Lower Monumental Dam, daytime spill started on 4 May and lasted until 18 June (Figure 52). Unit 3 was out of service for the entire spill season but the other turbines operated continuously except for short, intermittent outages. Continuous daytime spill began on 1 May at Little Goose Dam and continued until 19 June (Figure 53). Unit 4 was off line for virtually all of the spill season and unit 5 was out of service from the beginning of the season to 13 May and then provided intermittent service through the end of the spill season. Daytime spill occurred continuously from 13 to 31 May and intermittently until 9 June at Lower Granite Dam (Figure 54). All turbines operated virtually continuously throughout the spill period with short, intermittent outages occurring at each unit.

The spill pattern test period was initiated at each dam on 14 May 1993 by spilling the pattern regularly used for adult fish passage (as indicated by the U.S. Army Corps of Engineers Fish Passage Plan) and alternated daily starting at 0400 h with the scheduled pattern. The test period at each dam lasted as long as there was regular daytime spill.

The regular and alternate spill patterns at Ice Harbor Dam were both dome shaped patterns (Figure 55). The regular spill pattern was shaped so the majority of the spill was discharged from spillbays 4-6, whereas the alternate spill pattern was shifted to the north and had the majority of the discharge from spillbays 5-7 at most levels of spill. The maximum gate openings were distributed similarly at all levels of spill for both spill patterns except at 80 and 100 kcfs when the maximum gate openings were at one or two gates (5 and 6) for the regular spill pattern and three gates (5-7) during the alternate pattern.

The regular spill pattern at Lower Monumental Dam was generally flat shaped but with the maximum discharge from one or both of the end spillbays at most levels of spill (Figure 56). The alternate spill pattern was dome shaped so the majority of the spill was discharged from spillbays 4-5 and tapered to the least amount from gates 2 and 7.

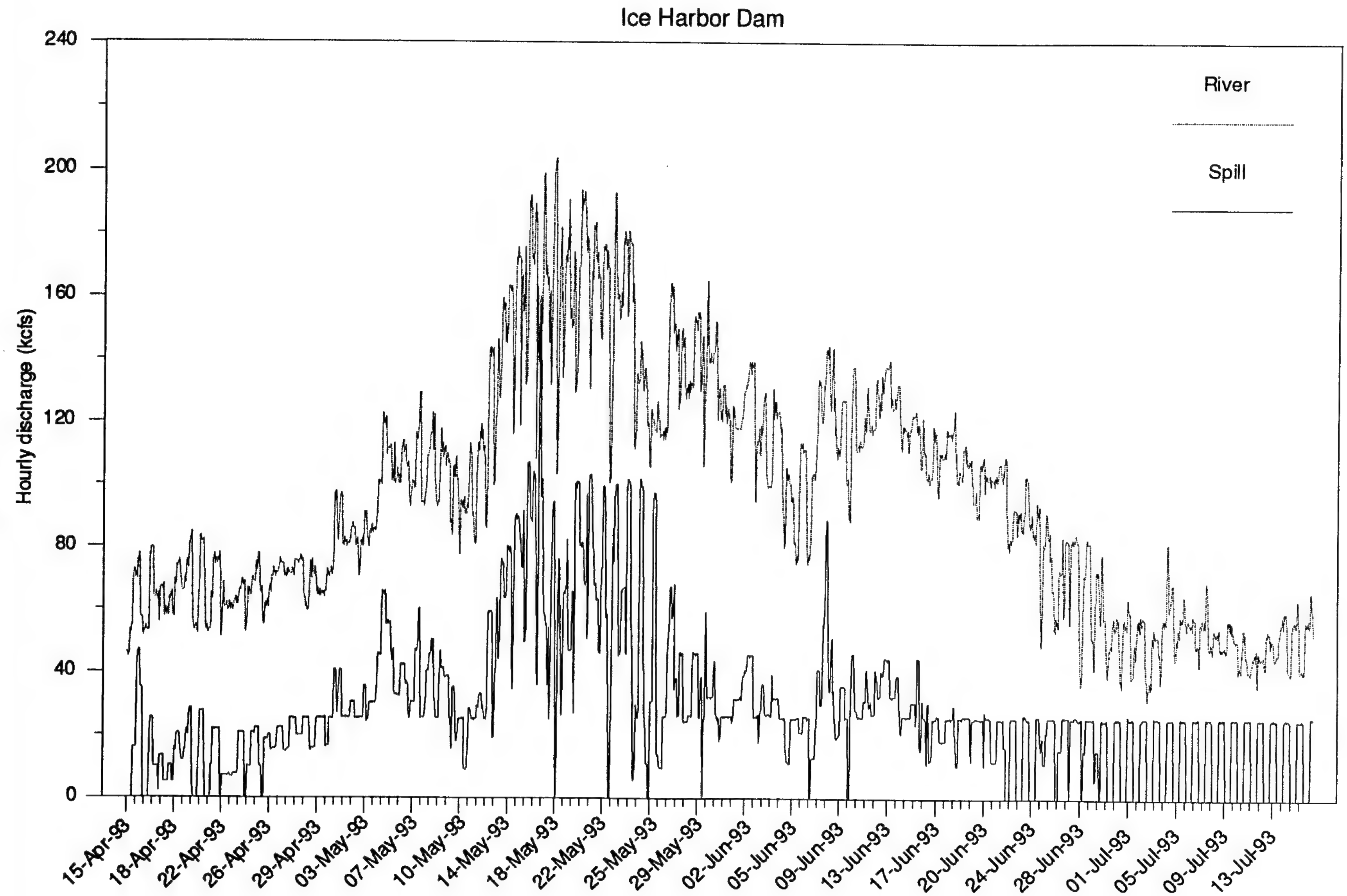


Figure 51. Hourly river discharge and hourly spill at Ice Harbor Dam from 15 April through 15 July 1993.

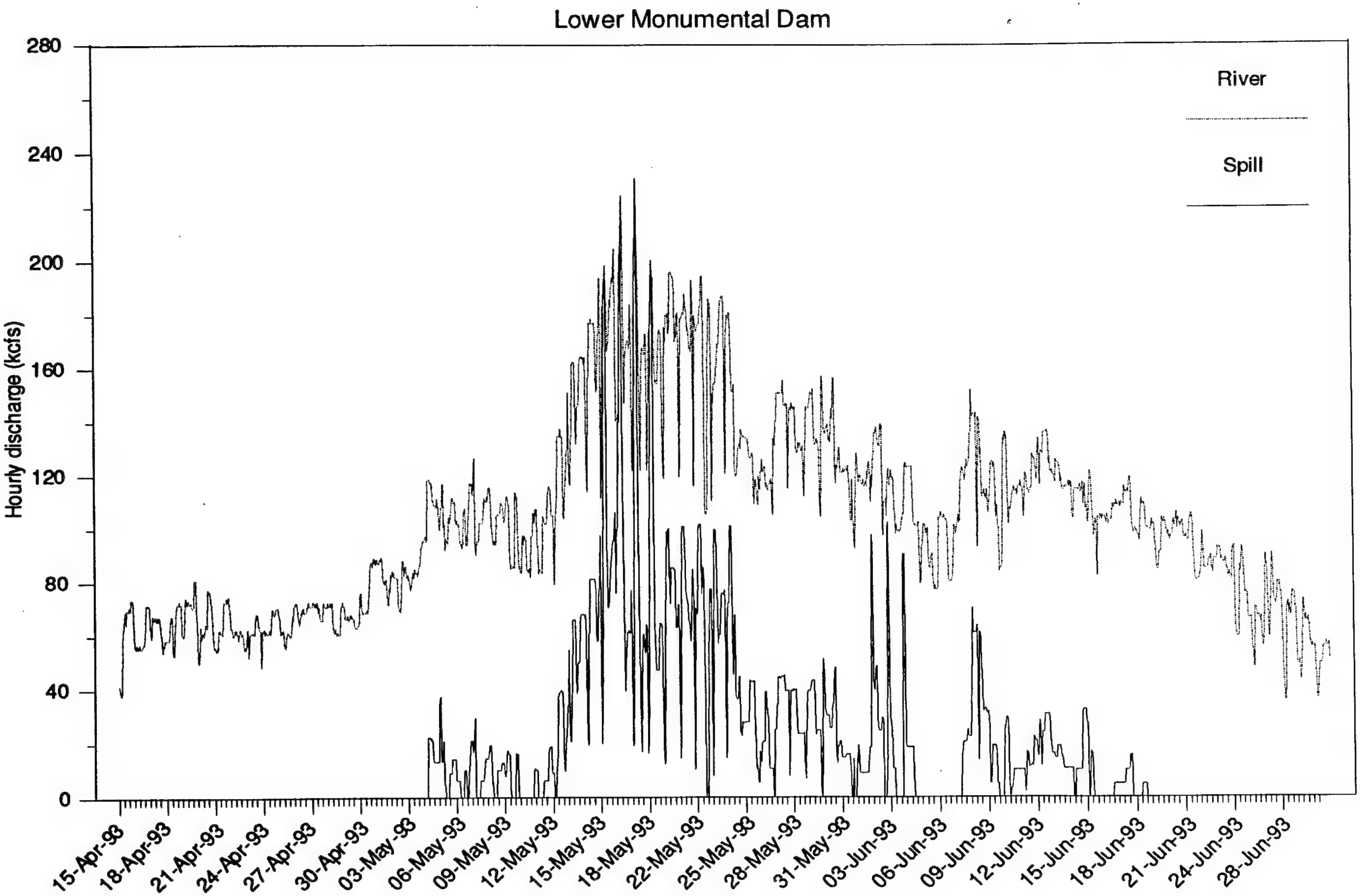


Figure 52. Hourly river discharge and hourly spill at Lower Monumental Dam from 15 April through 30 June 1993.

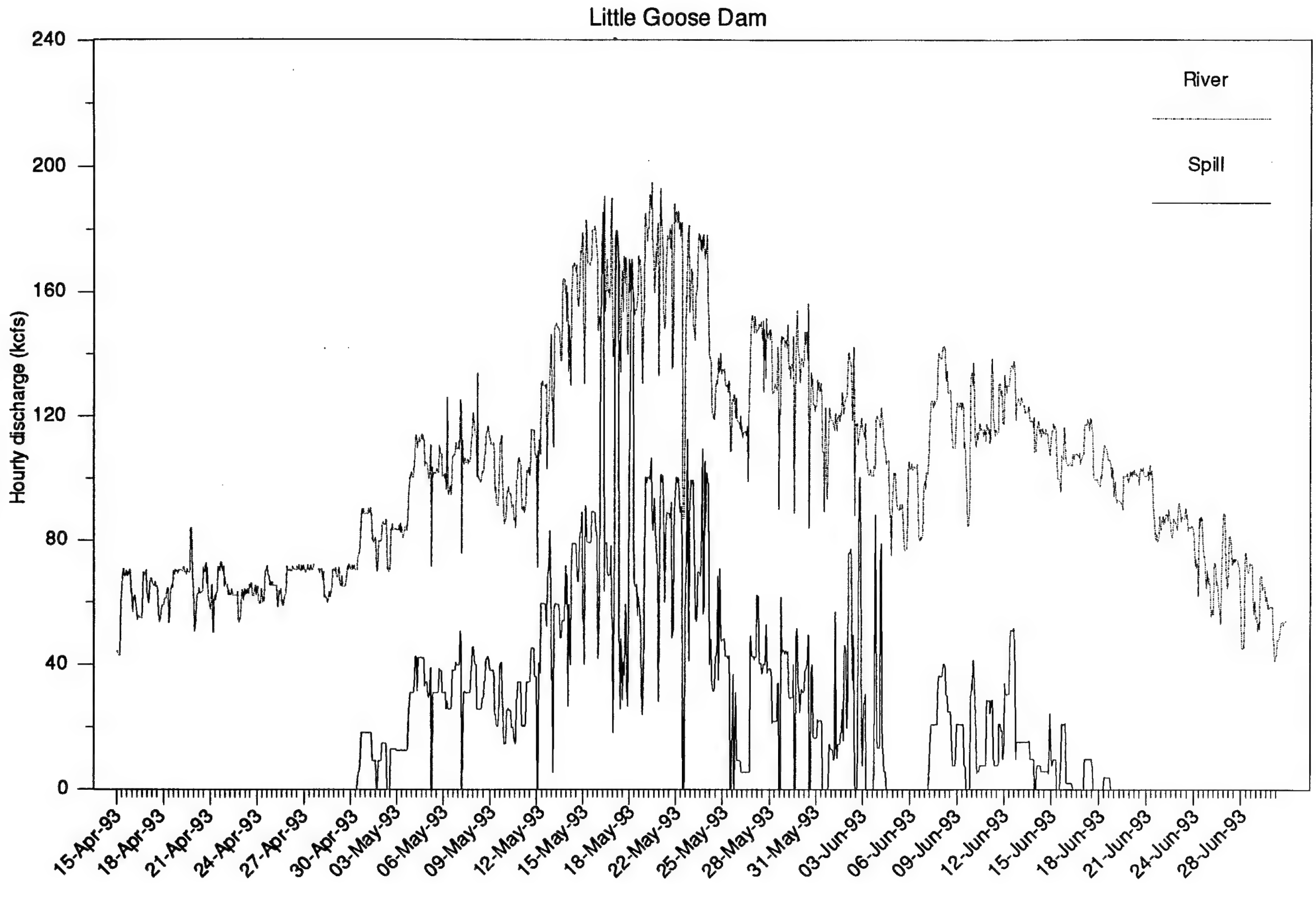


Figure 53. Hourly river discharge and hourly spill at Little Goose Dam from 15 April through 30 June 1993.

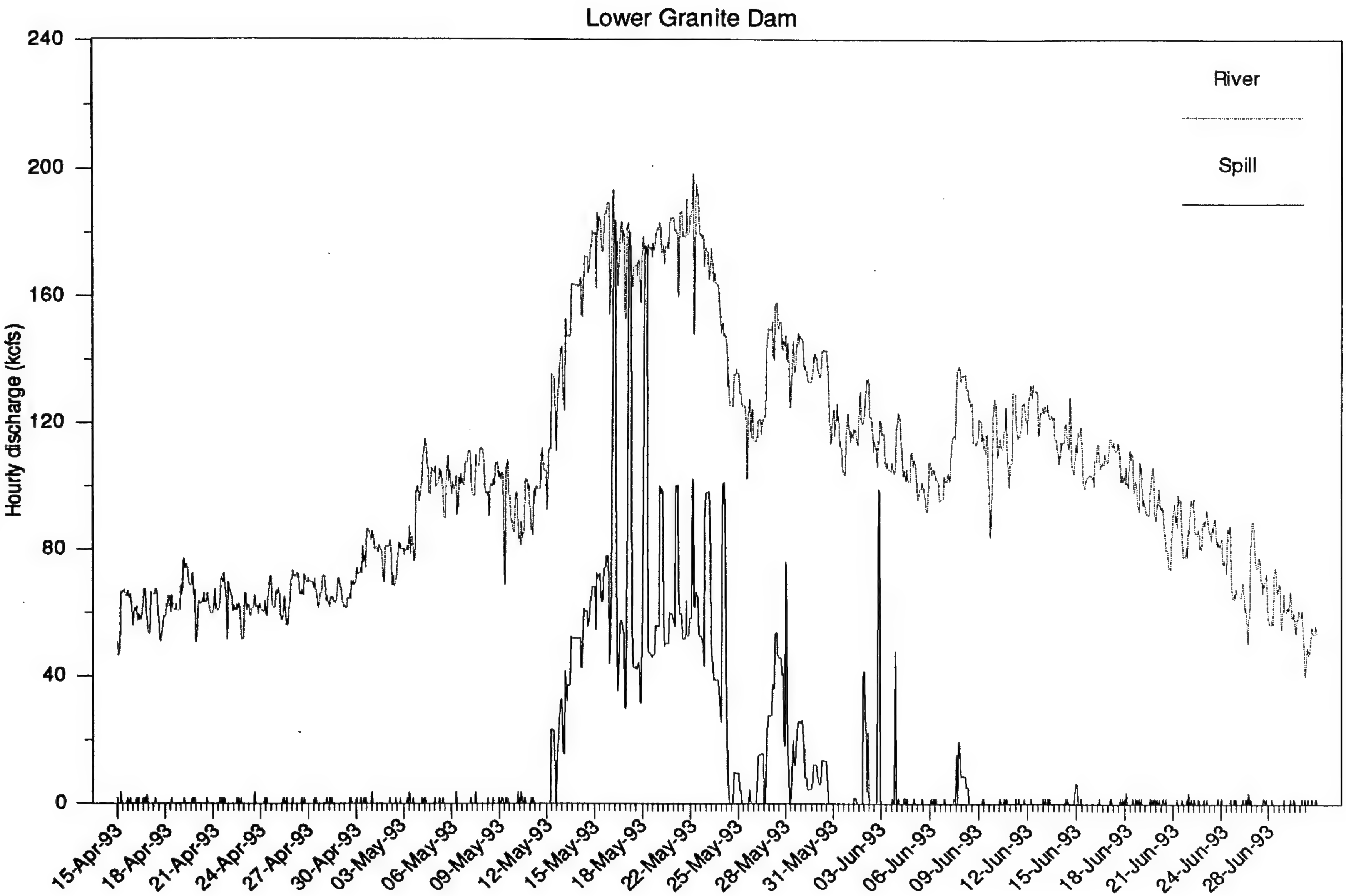


Figure 54. Hourly river discharge and hourly spill at Lower Granite Dam from 15 April through 30 June 1993.

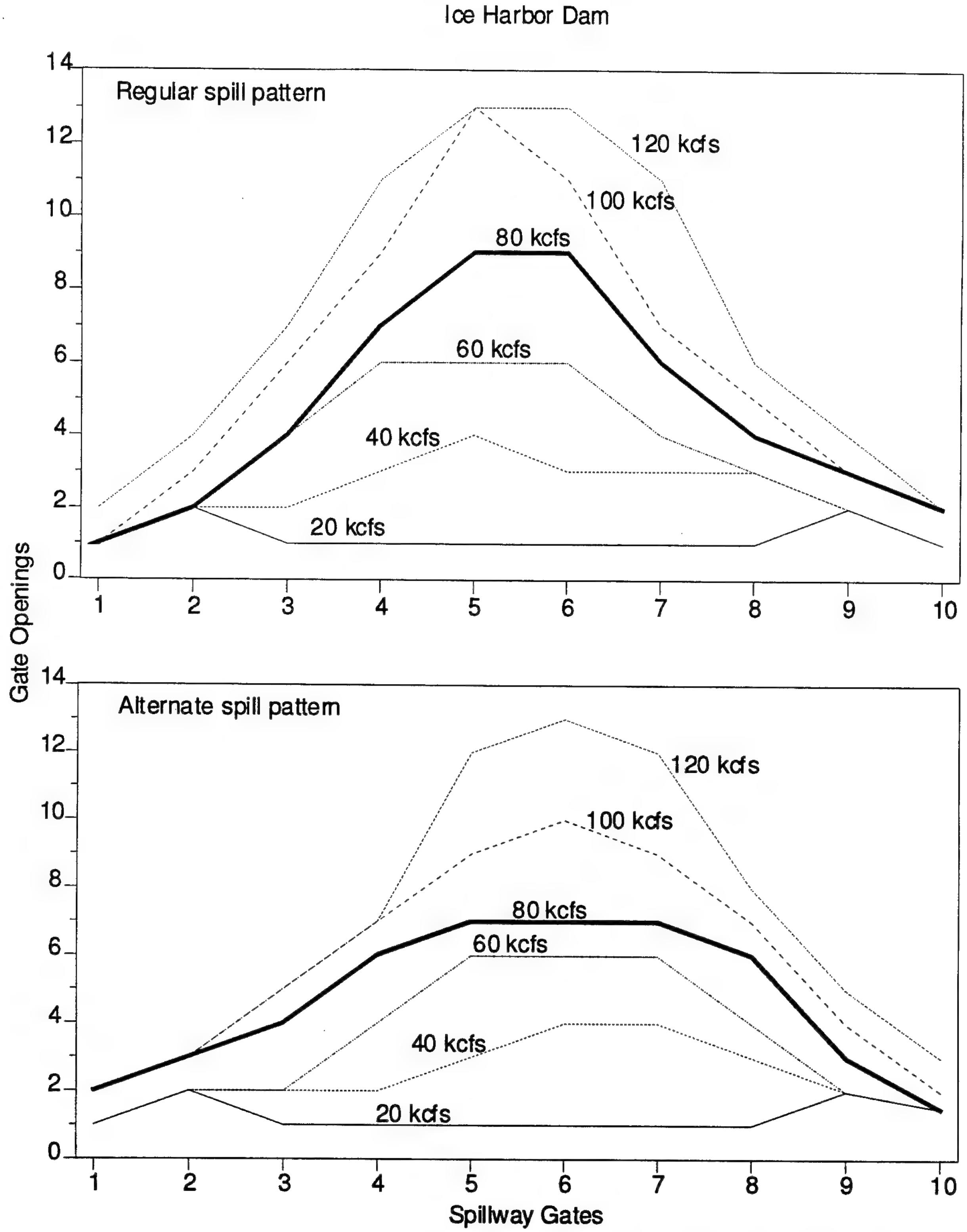


Figure 55. Gate openings for each spillway gate at Ice Harbor Dam during the regular and alternate spill patterns from 20 - 120 kcfs in 20 kcfs increments in 1993.

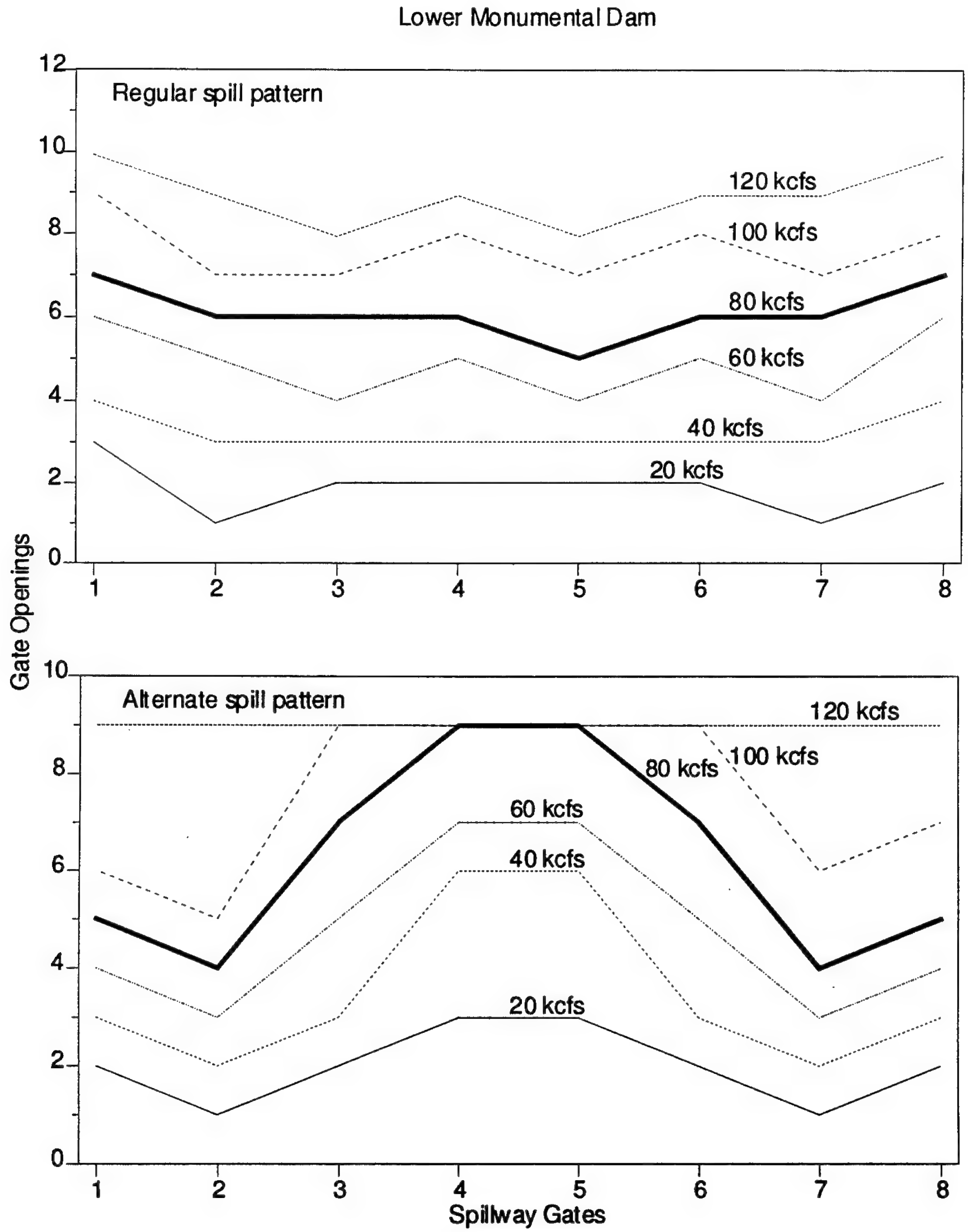


Figure 56. Gate openings for each spillway gate at Lower Monumental Dam during the regular and alternate spill patterns from 20 - 120 kcfs in 20 kcfs increments in 1993.

The regular spill pattern at Little Goose Dam was generally uniform shaped with the maximum discharge from the end spillbays and the least from bays 5 and 6 (Figure 57). The alternate spill pattern was dome shaped so the majority of the spill was discharged from spillbays 4 and 5, tapered down to the least spill from bays 2 and 7 and intermediate amounts of spill from the end spillbays.

The regular spill pattern at Lower Granite Dam was angled to the south with the maximum discharge from spillbays 2-5 and the least from spillbays 7 and 8 (Figure 58). The alternate spill pattern was more dome shaped up to 80 kcfs with the majority of the flow being discharged from spillbays 3-5 and tapered down to release the least spill from the end bays. Both spill patterns were uniform shaped at 100 and 120 kcfs to help control dissolved gas levels.

U. S. Army Corps of Engineers and University of Idaho personnel video taped the regular and alternate spill patterns at various levels of daytime spill (0600 h to 2100 h) at each of the lower Snake River dams. Daytime spill was divided into low (0.1-39.9 kcfs), medium (40.0-79.9 kcfs) and high (>80 kcfs) levels. Areas of turbulence and currents during the different spill patterns and levels of spill were interpreted from video taped images and notes made while observing spill.

To understand the effect of spill patterns on fish behavior in the tailrace we analyzed the time elapsed from when a fish entered the tailrace to when it first entered the fishway system and which entrance was first used during both spill patterns at each dam using the radio telemetry receivers and fish with radio transmitters. Both variables (time to first entry and location of first entry) were analyzed for fish that were in the tailrace and entered the fishways after being exposed to only one treatment (i.e. on a day with the regular spill pattern at low levels of spill). Fish in the tailrace long enough to be exposed to two or more spill patterns were not included in the analysis because we could not tell which spill pattern they were responding to, if any. Fish exposed to two spill patterns usually took longer than 18 h to first enter the fishway. However, a few fish arrived in the tailrace during nighttime hours (for example 0200 h) and made their first entry at dawn (0600 h). These fish were exposed to two treatments because the spill pattern changed at 0400 h, but the time to the first entry would be 4 h.

In addition to the statistically designed comparisons between spill patterns, a general comparison was made for the period of no spill versus the spill patterns. The longest spill period was 47 d (14 May - 29 June) at Ice Harbor Dam and chinook salmon continued to pass through the lower Snake River dams until the end of August (Figures 59, 60, 61, 62).

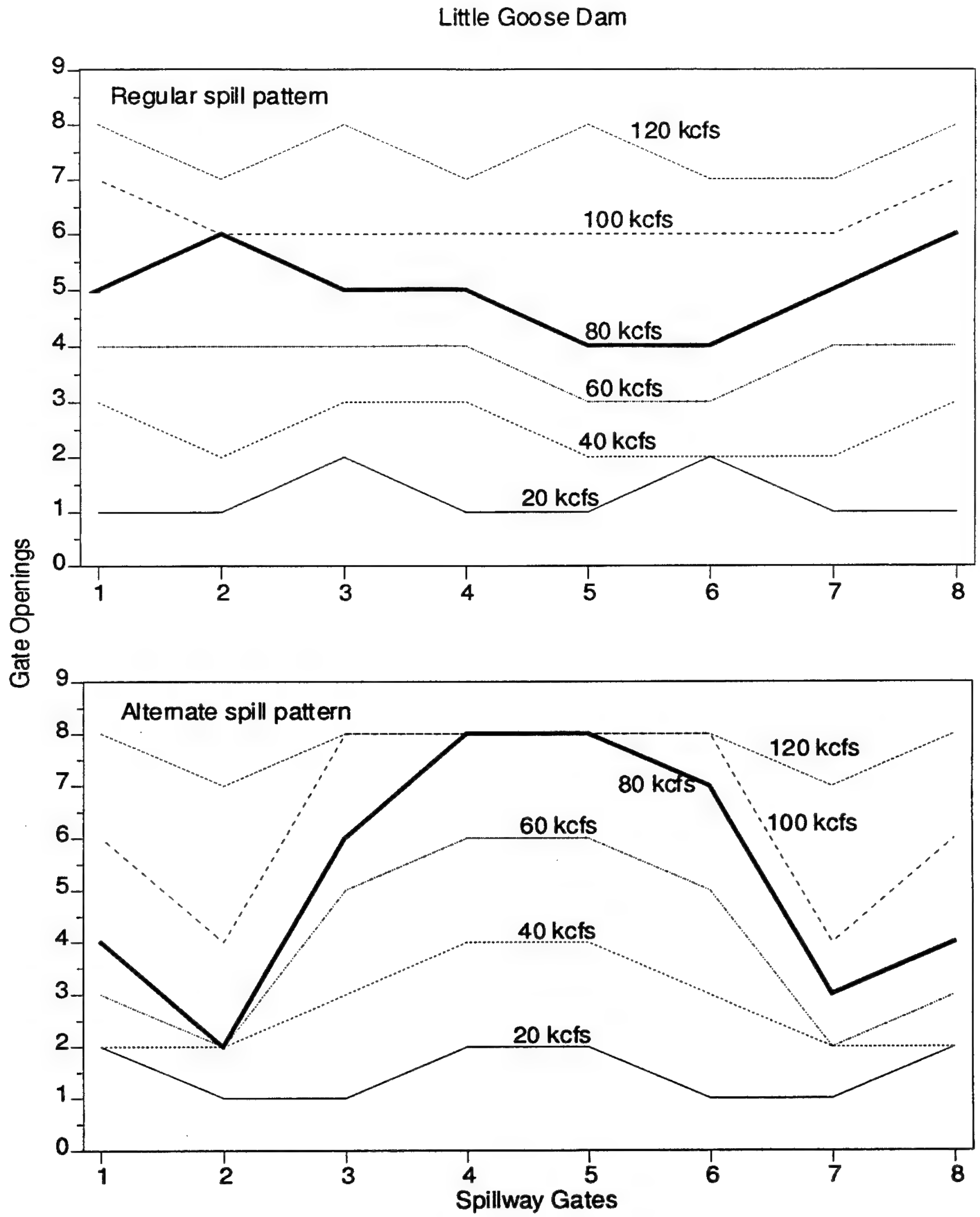


Figure 57. Gate openings for each spillway gate at Little Goose Dam during the regular and alternate spill patterns from 20 - 120 kcfs in 20 kcfs increments in 1993.

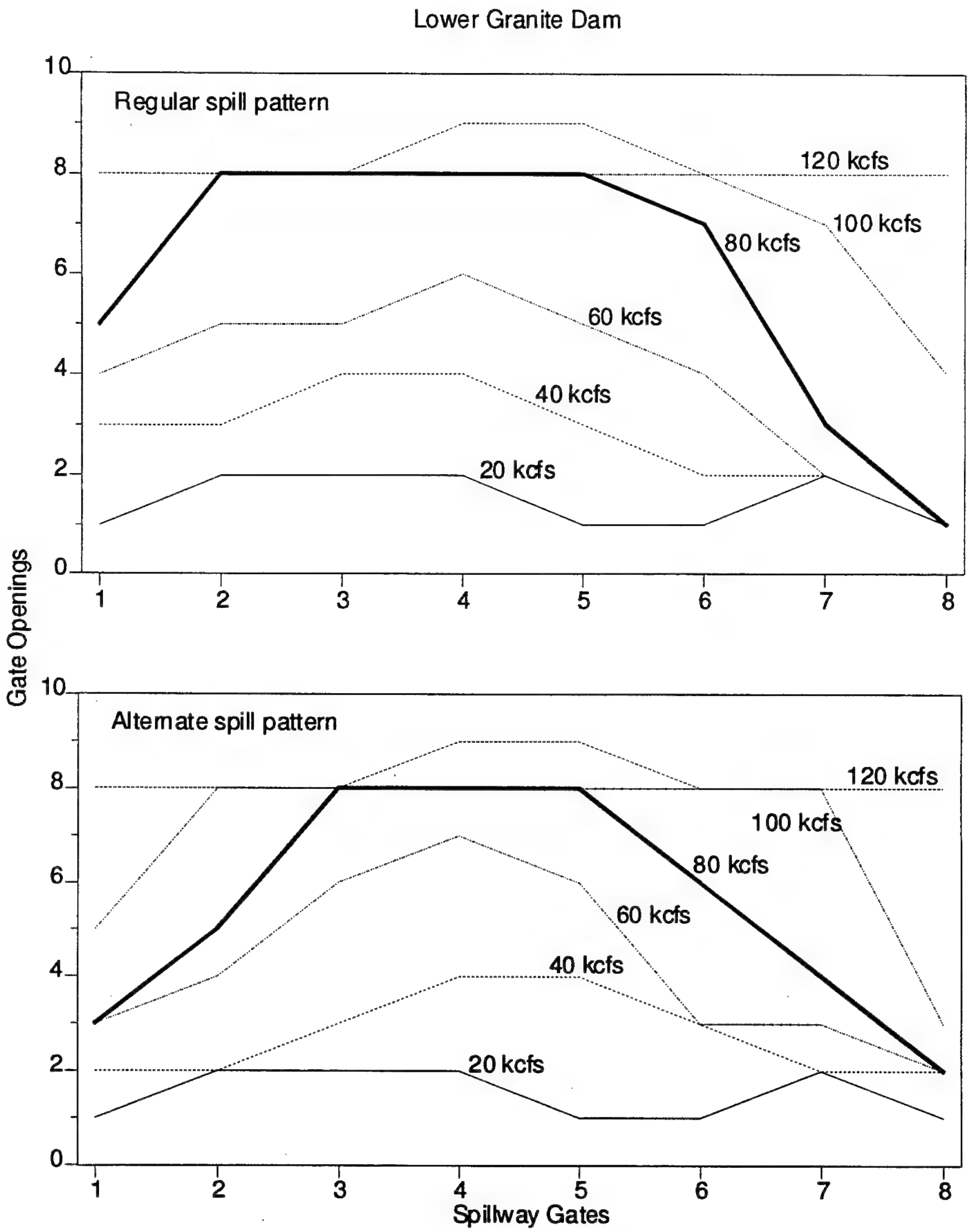


Figure 58. Gate openings for each spillway gate at Lower Granite Dam during the regular and alternate spill patterns from 20 - 120 kcfs in 20 kcfs increments.

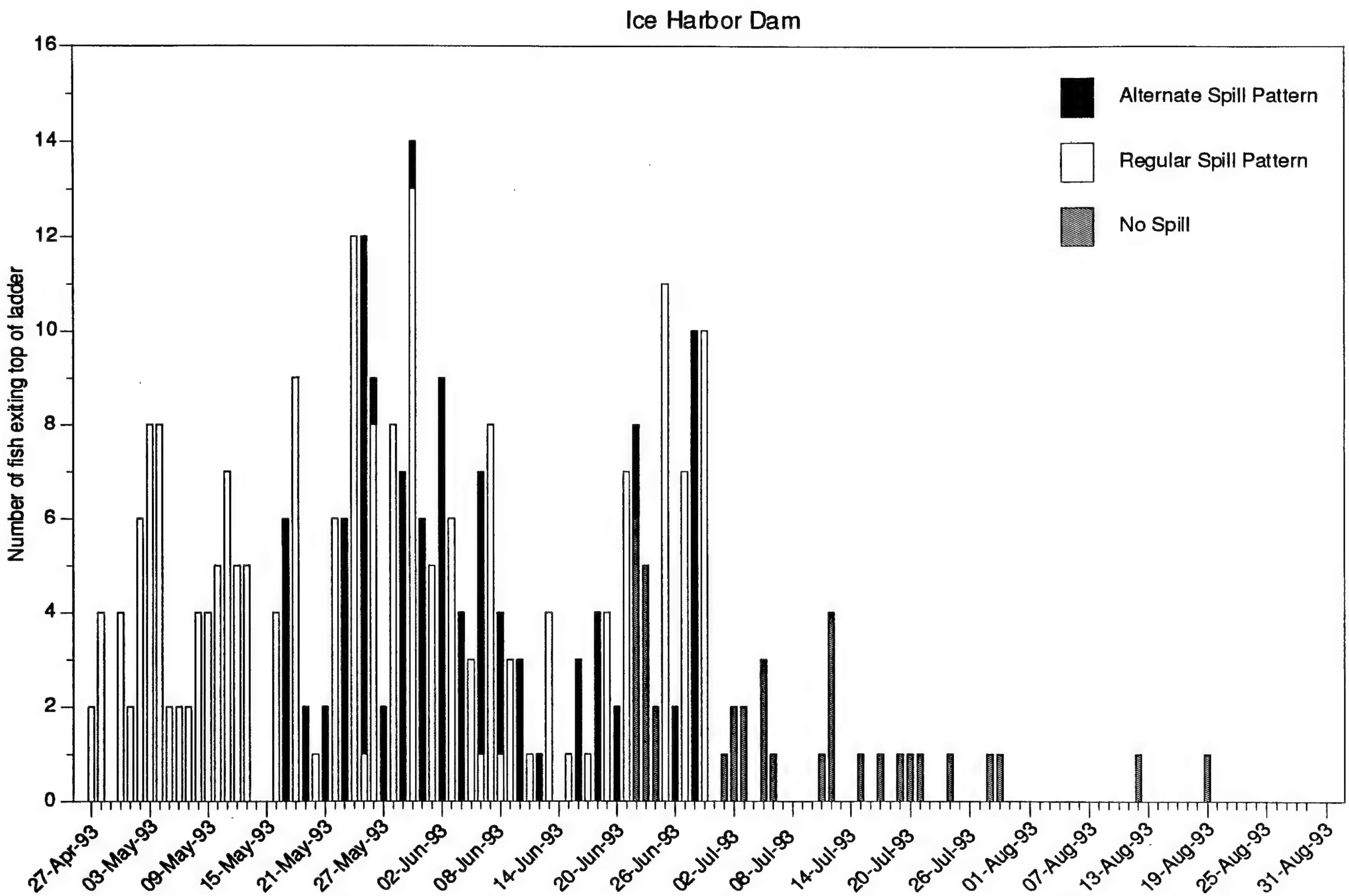


Figure 59. Timing of chinook salmon outfitted with radio transmitters passing Ice Harbor Dam during the regular and alternate spill patterns or no spill conditions in 1993.

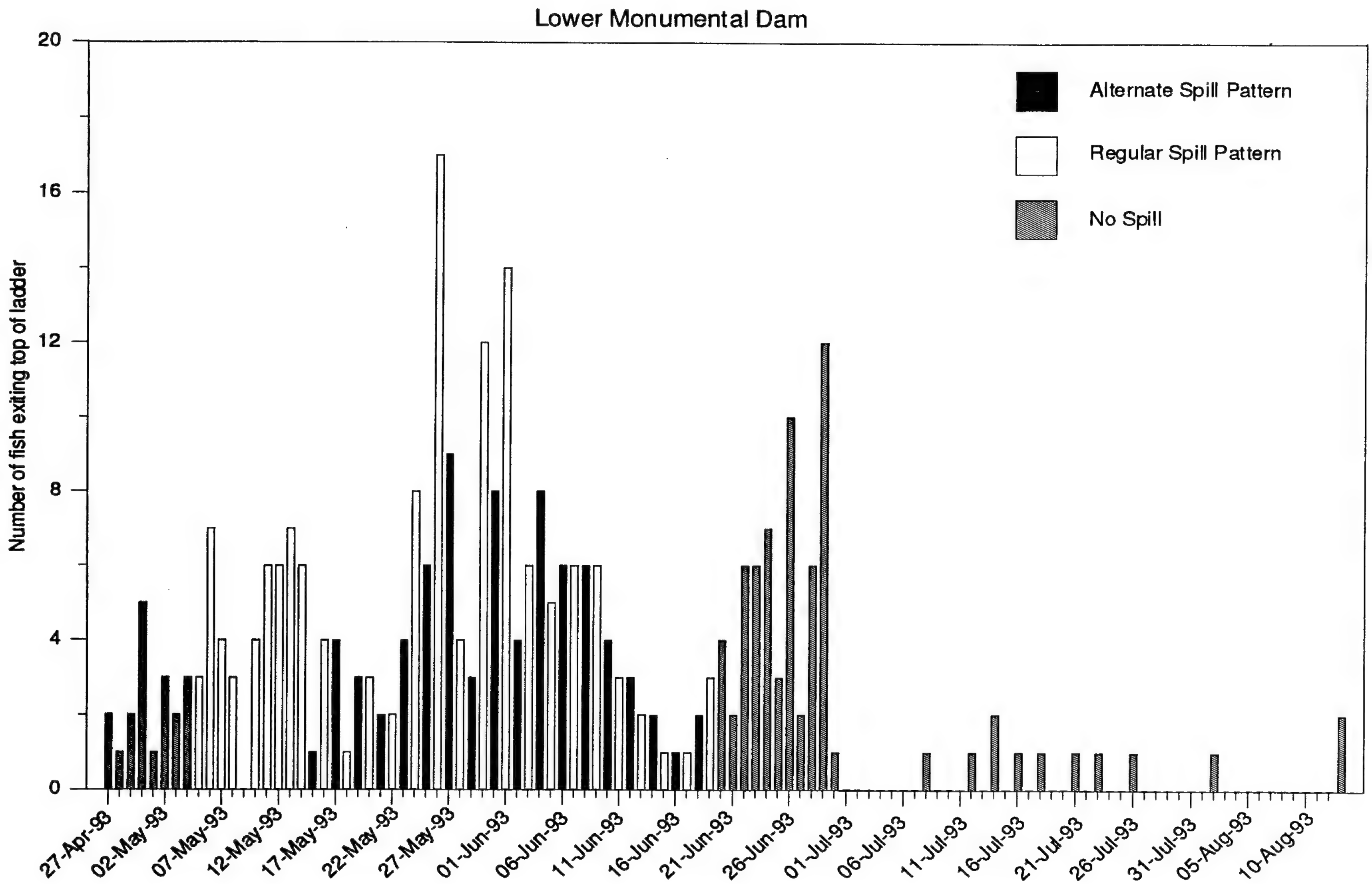


Figure 60. Timing of chinook salmon outfitted with radio transmitters passing Lower Monumental Dam during the regular and alternate spill patterns or no spill conditions in 1993.

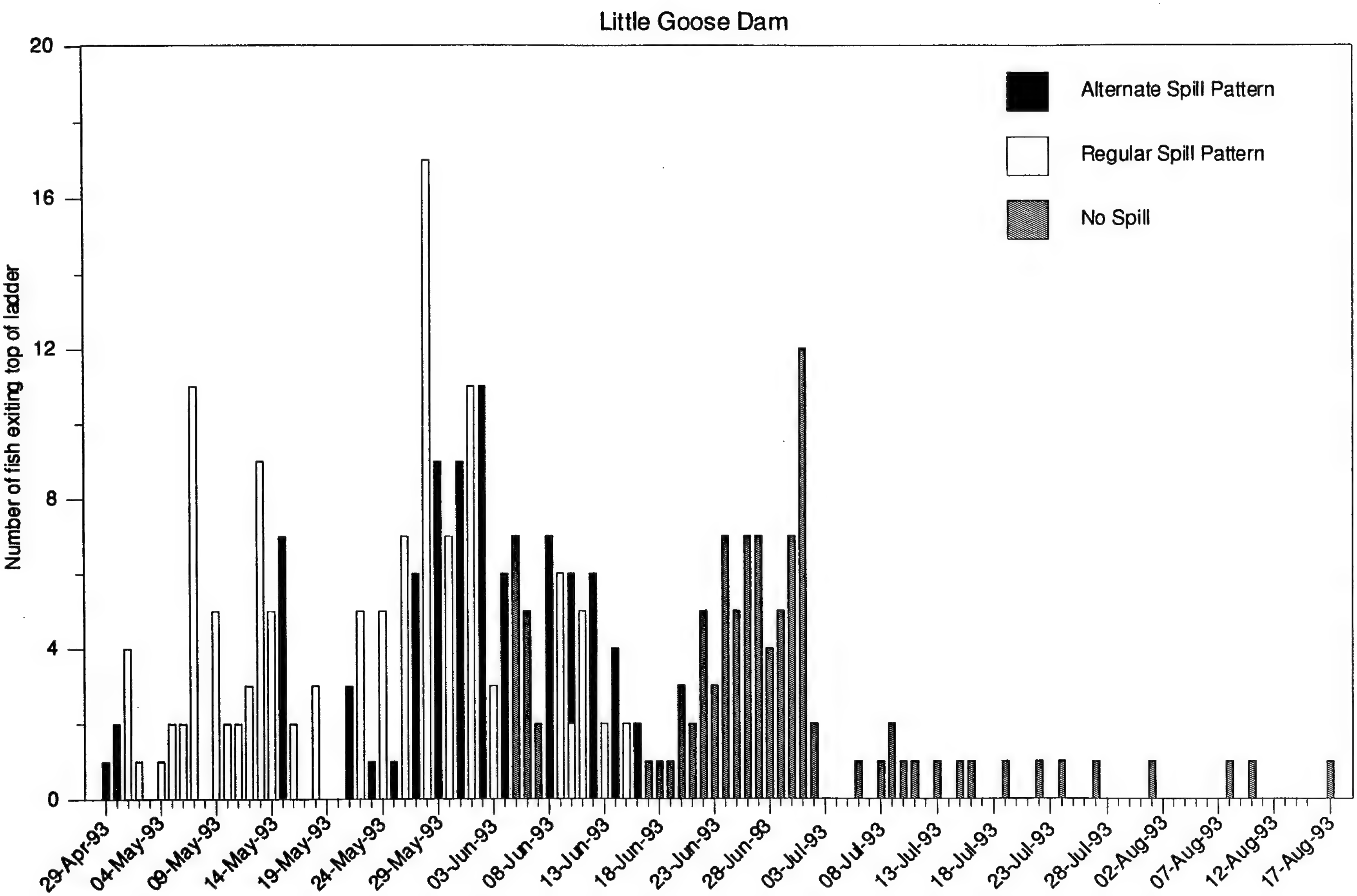


Figure 61. Timing of chinook salmon outfitted with radio transmitters passing Little Goose Dam during the regular and alternate spill patterns or no spill conditions in 1993.

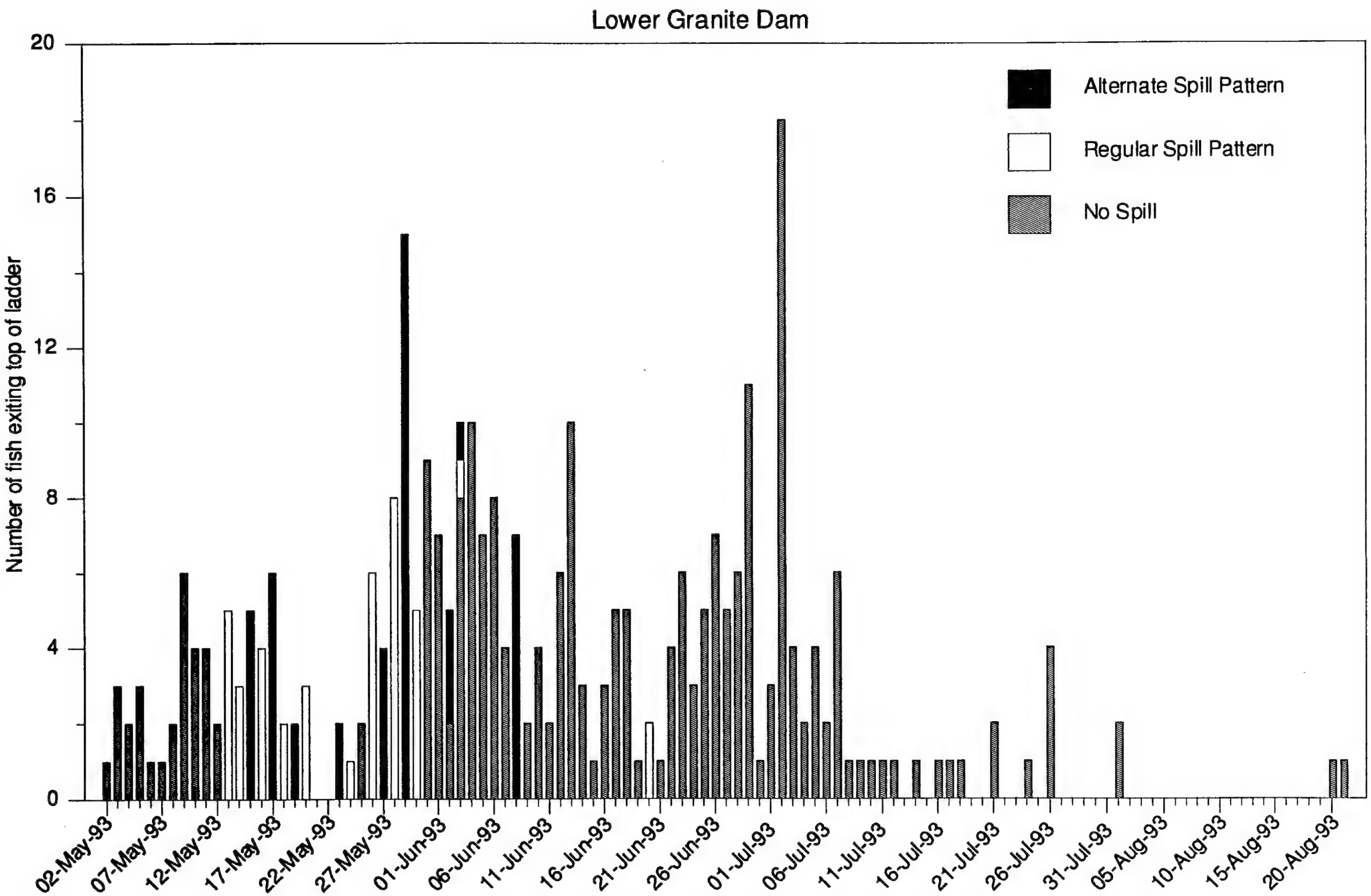


Figure 62. Timing of chinook salmon outfitted with radio transmitters passing Lower Granite Dam during the regular and alternate spill patterns or no spill conditions in 1993.

No Spill Period

The median time to first entry at Ice Harbor Dam during no spill was 1.8 h and varied between 2.5 and 2.9 h at the other three dams (Figure 63). At Ice Harbor Dam, 22 of 23 fish we collected complete records from made the first entry into the fishway within 12 h of entering the tailrace. Eighty to 86% of the fish recorded at the remaining dams first entered the fishway within 12 h of entering the respective tailrace areas.

When there was no spill at each of the four dams, the majority of the entrances first used to enter the fishway were at either end of the powerhouse or at the entrance on the side opposite of the powerhouse with relatively few first entrances occurring at the orifice gates in the middle of the powerhouse (Figure 64). At Ice Harbor Dam, 11 of 33 fish first entered at the south shore entrance while 18% first entered at the north powerhouse entrance and 12% at the north shore entrance. At Lower Monumental Dam, about 35% of the fish first entered the fishway at the south shore ladder entrance, 38% first entered the via the south end of the powerhouse entrances (SPE-1 and -2), and 16% first entered the north shore entrance (NSE). At Little Goose Dam, more than half (55%) of the fish first entered the fishway at either the south shore entrance (SSE) or orifice gate 1 (OG-1), 23% first entered at the north powerhouse entrances NPE-1,-2, and -3 combined, and 8% entered at the north shore entrance. At Lower Granite Dam, approximately 25% of the fish entered the fishway for the first time through SSE-1, 9% first entered at OG-1, 13%, 23% and 1% of the fish first entered via the NPE-1, -2 and -3, respectively, (37% in total), and 7% entered at the north shore entrance.

Period With Spill

Ice Harbor Dam

Daytime spill began on 15 April 1993 and continued through 29 June after which water was spilled at night for juvenile fish passage (Figure 65). Within the test period (14 May-29 June) there were 23.5 days of the regular spill pattern and 21.8 days of the alternate spill pattern (Figure 66). Maximum hourly daytime spill was 107.1 kcfs recorded on 16 May at 0700 h (Figure 51). The period of highest daily average river discharge and highest daily average spill (15-23 May) generally coincided with fewer chinook salmon being recorded at the counting windows as compared to the remainder of the spill season (Figure 65). A drop in daily average spill from 86.3 kcfs (16 May) to 56.7 kcfs (18 May) coincided with the number of chinook salmon counted at the windows increasing from 165 to 453, respectively. As spill increased to 82.2 kcfs on 20 May fish counts decreased to 62, but then increased to 775 fish on 24 May as spill decreased to 51.4 kcfs.

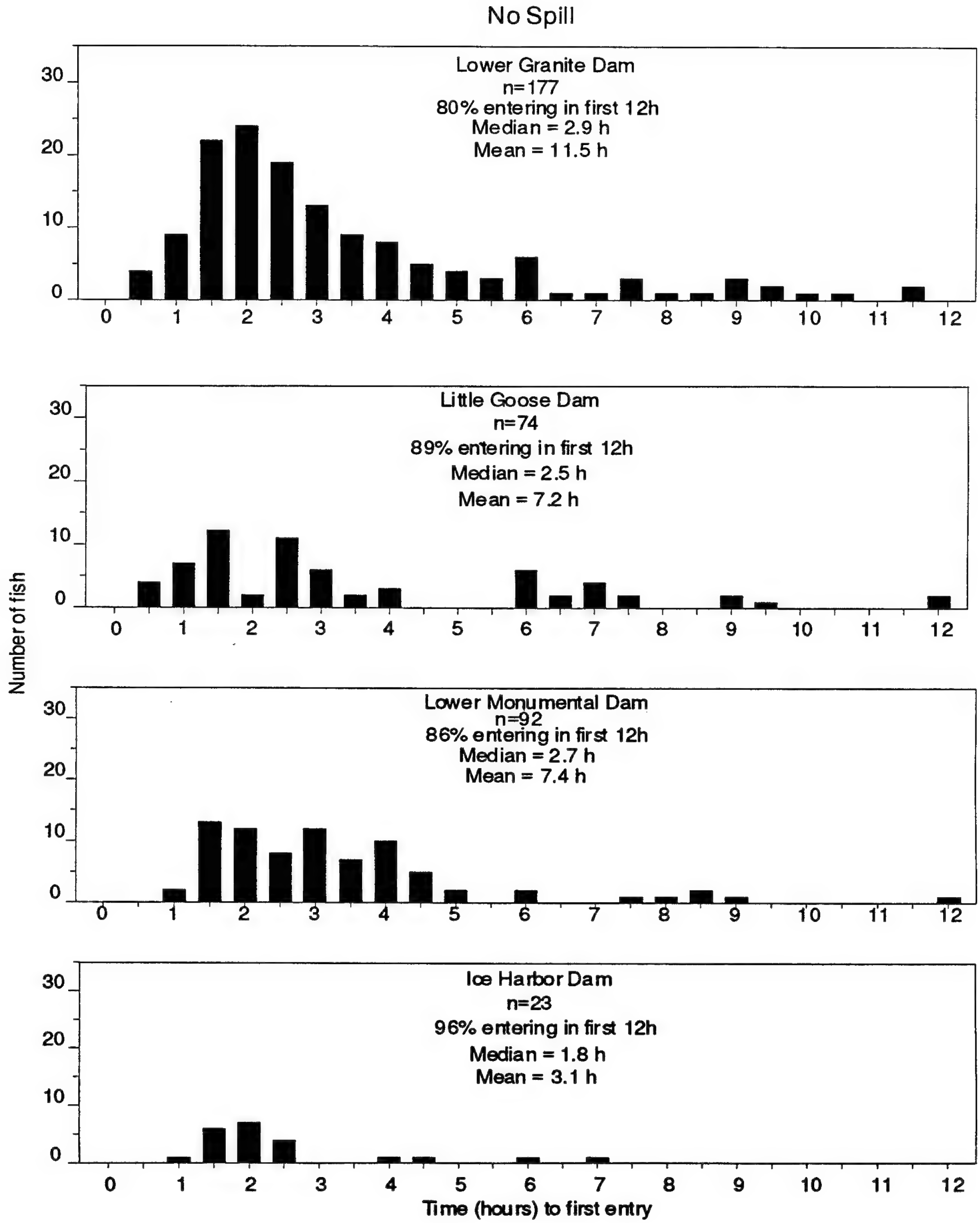


Figure 63. The number of chinook salmon and the elapsed time between entry into the tailrace and first entry into a fishway at each of the lower Snake River dams when there as no daytime spill in 1993.

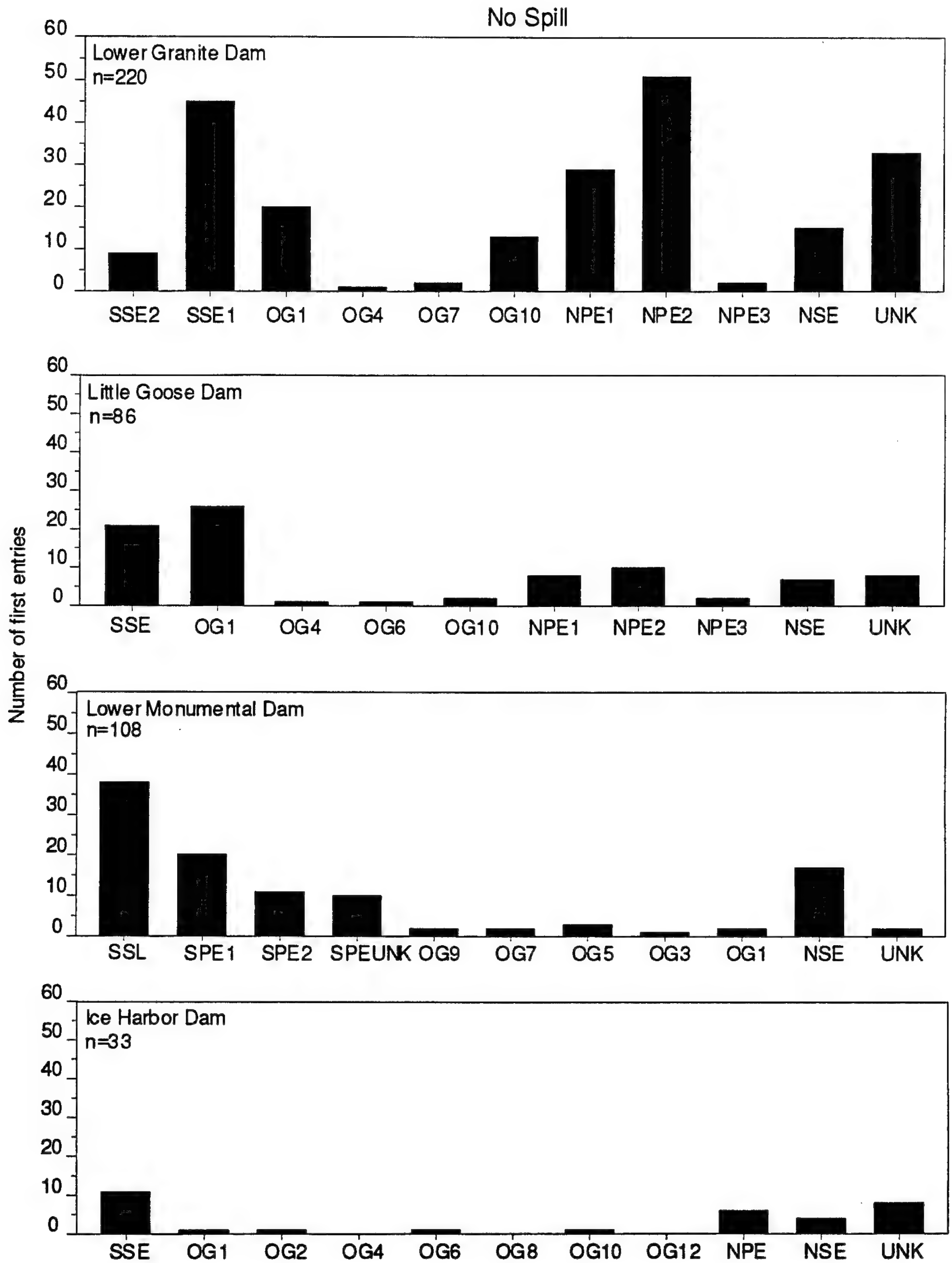


Figure 64. Entrances used by chinook salmon at each of the lower Snake River dams when entering the fishways the first time during no spill conditions in 1993.

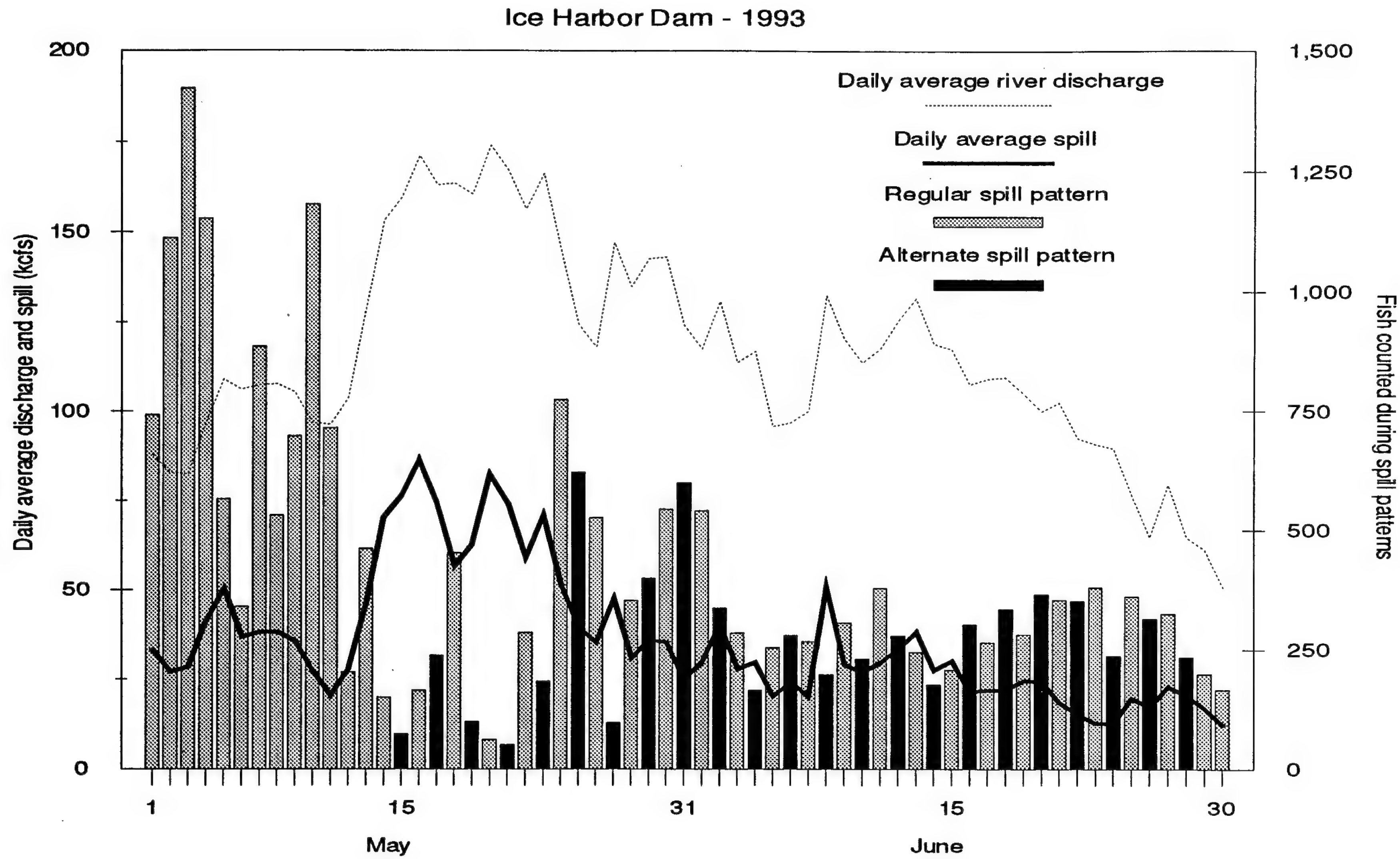


Figure 65. Daily average discharge and spill, and the number of chinook salmon observed at the north and south ladder counting windows (bars) at Ice Harbor Dam on days with regular or alternate spill patterns or no spill conditions from 1 May - 30 June 1993.

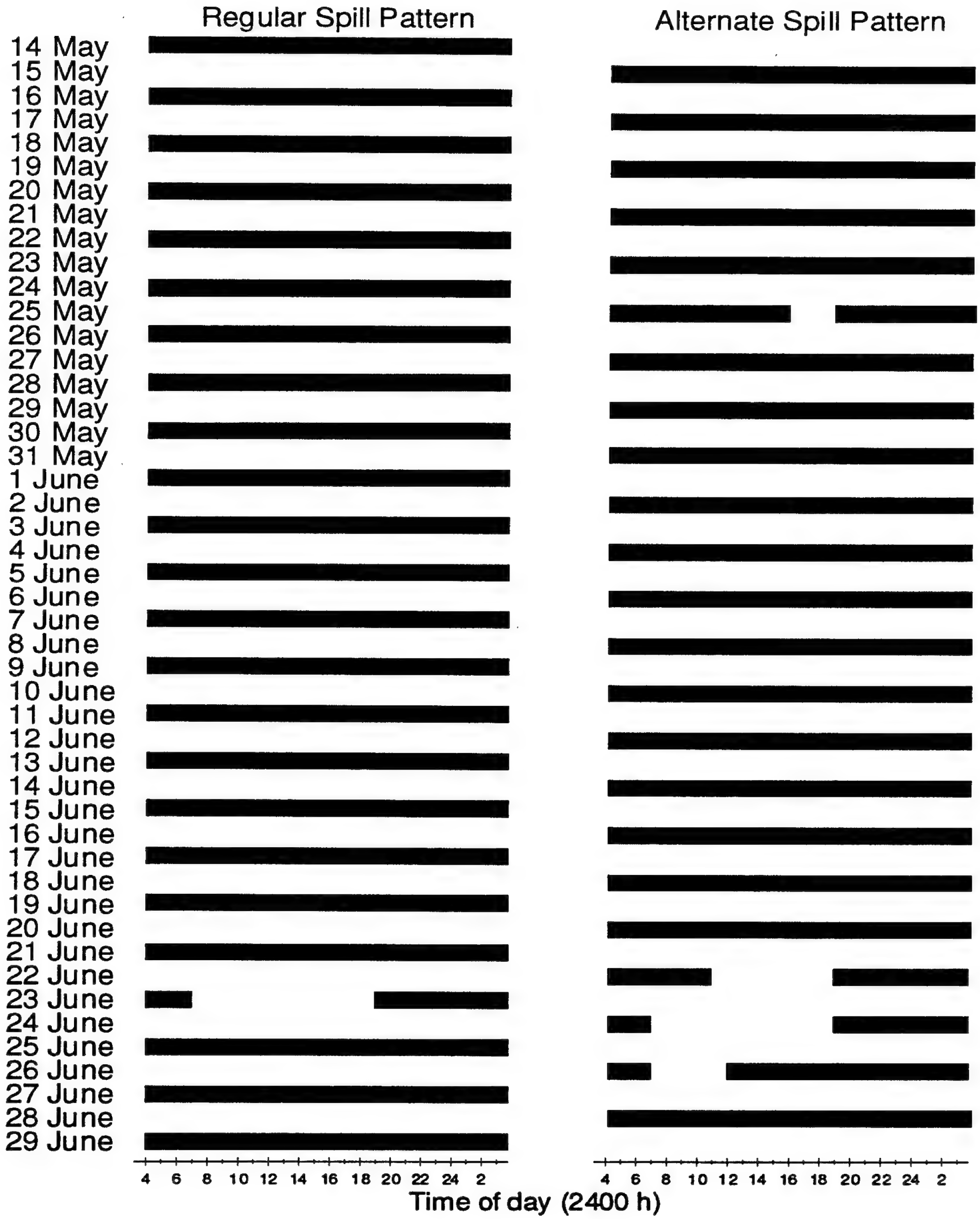


Figure 66. Duration of the regular and alternate spill patterns at Ice Harbor Dam in 1993.

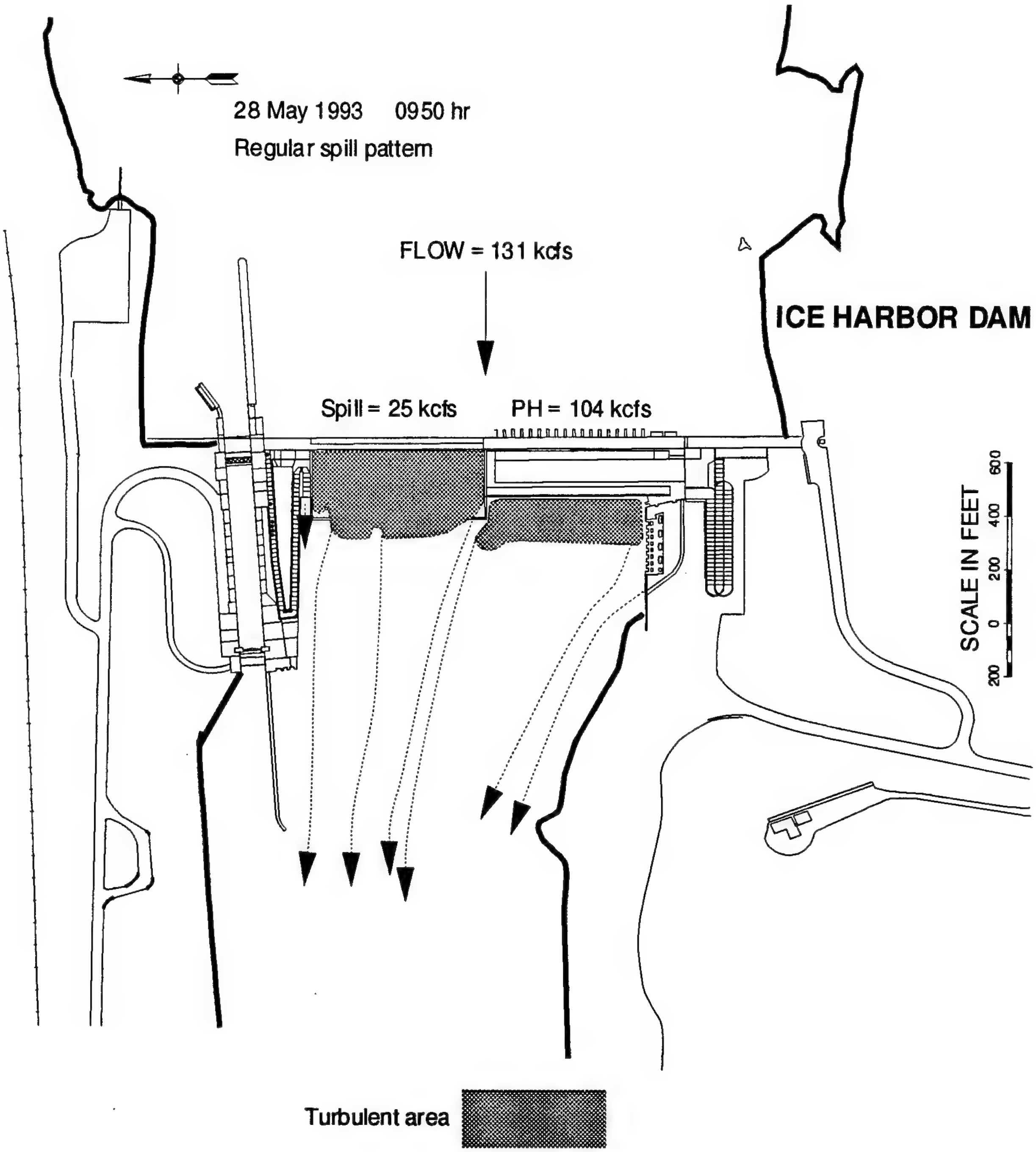


Figure 67. Flow patterns downstream from Ice Harbor Dam during the regular spill pattern at low spill levels (25 kcfs) as interpreted from video tape images and notes made at the time of spill.

At the lower levels of spill (<40 kcfs), flow patterns in the tailrace during the regular and alternate spill patterns were difficult to distinguish (Figure 67; Appendix A, Figure A1). The area of surface turbulence from the spill discharge was across the width of the

spill basin and extended downstream beyond, but did not block the entrance to the north shore fishway. At medium levels of spill (40-80 kcfs), surface turbulence from the spill during the alternate pattern extended downstream about as far as the entrance to the lock (Figure 68; Appendix A, Figure A2). The southern edge of the surface turbulence tapered to the north over the entire length while the north edge was confined by the lock wall. An eddy formed immediately downstream of the north shore entrance on 21 and 27 May (Appendix A, Figure A3), but was not present on 23 May when the turbulence extended up to the lock wall. At high levels of spill (> 80 kcfs) the surface turbulence from the spill discharge extended downstream to between the entrance to the lock and the downstream end of the guide wall (Figure 69; Appendix A, Figure A4). The south edge of the regular spill pattern was pushed to the north by the powerhouse discharge and the north edge extended up to the lock wall. During both patterns the area in front of the north shore entrance was very turbulent. At all levels of spill, boils of turbine discharge water from the operating turbines were obvious about 10 m downstream of the powerhouse. Currents in the tailrace generally flowed directly downstream during both spill patterns at low and medium levels of spill, however, an eddy formed along the north shore downstream of the lock guide wall during both spill patterns at high spill levels.

At low spill levels, 40 chinook salmon were available in the tailrace and made their first entry into the fishway while exposed to only the regular spill pattern and took a median of 2.5 h to enter the fishway compared to 2.1 h for fish (n = 34) entering during the alternate spill pattern (Figure 70). There were an additional 23 fish that entered the fishway for the first time during the regular spill pattern at low levels of spill after having been exposed to both spill patterns and they took between 4.9 h and 13.3 days to enter. An additional 11 fish entered the fishway during the alternate spill pattern at low spill levels that were exposed to both spill patterns and they took between 2.9 h and 1.7 days to do so.

At medium levels of spill, there were no fish that entered the fishway after being exposed to only the regular spill pattern, but there were nine fish that entered during the alternate spill pattern and took a median of 2.6 h. Of the fish exposed to both spill patterns before entering the fishway, one entered the fishway during the regular spill pattern and took 2.2 days, with an additional four fish entering the fishway during the alternate spill pattern and taking between 8.8 h and 1.5 days to do so. One fish with a transmitter was recorded entering the fishway at high levels of spill during the regular spill pattern, and it took 6.3 d to enter after passing into the tailrace area.

Chinook salmon that made their first entry into the fishway while exposed to only one spill pattern, used the south and north shore entrances plus the north powerhouse entrances most often (Figure 71). During the regular spill pattern and at low levels of spill, 35% of the first entrances were at north shore entrance, 20% at north powerhouse entrance and 12.5% at south shore entrance. During the alternate spill pattern, 47% of

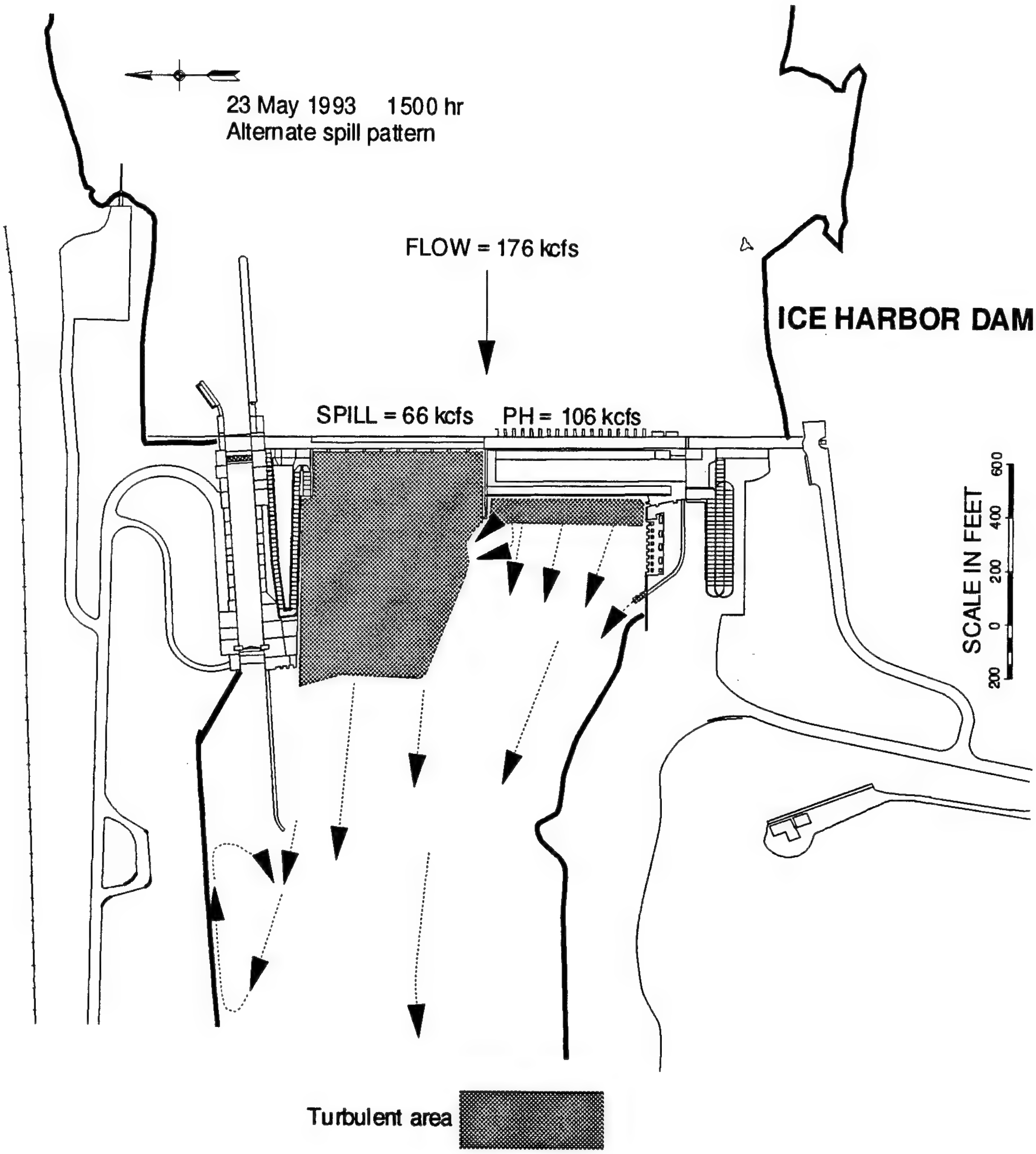


Figure 68. Flow patterns downstream from Ice Harbor Dam during the alternate spill pattern at medium spill levels (66 kcfs) as interpreted from video tape images and notes made at the time of spill.

the first entrances occurred at the north shore entrance and 18% at south shore entrance. During the alternate spill pattern at medium levels of spill, fish entered the

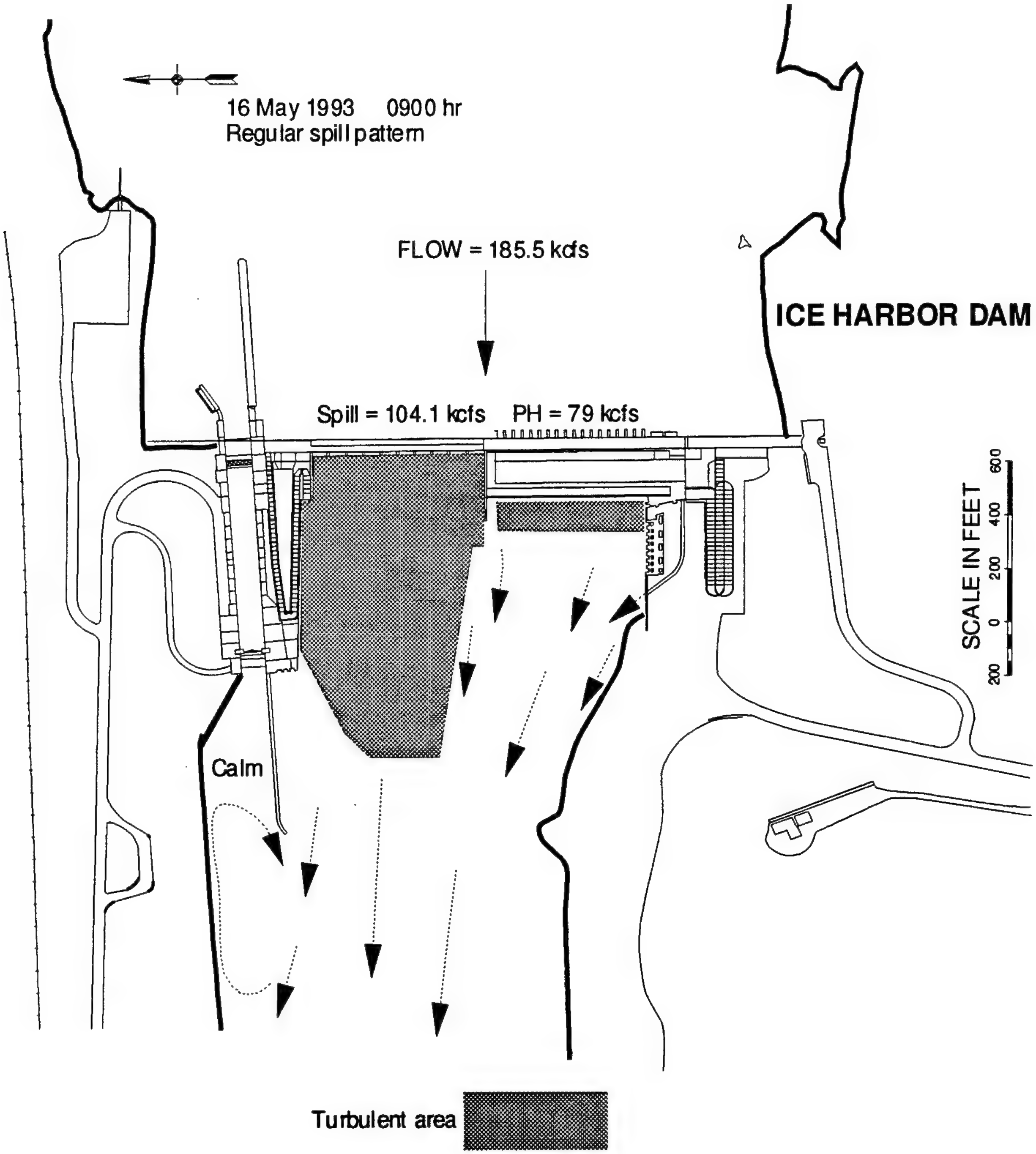


Figure 69. Flow patterns downstream from Ice Harbor Dam during the regular spill pattern at a high spill level (104 kcfs) as interpreted from video tape images and notes made at the time of spill.

fishway equally across most entrances, except 33% entered at the north powerhouse entrances.

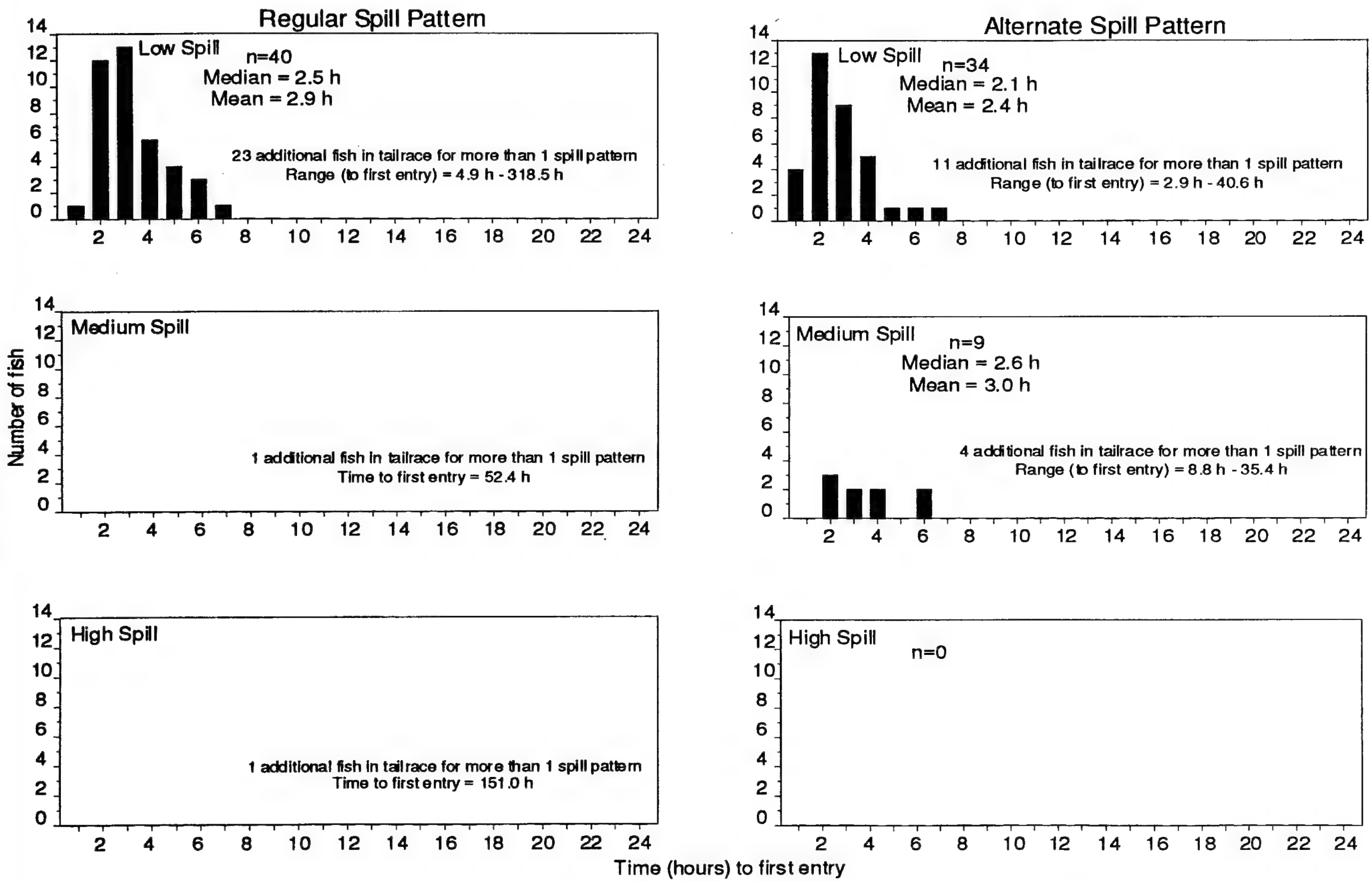


Figure 70. The number of chinook salmon and the elapsed time from entry into the tailrace to first entrance into the fishway at Ice Harbor Dam during regular and alternate spill patterns at low, medium, and high spill levels in 1993.

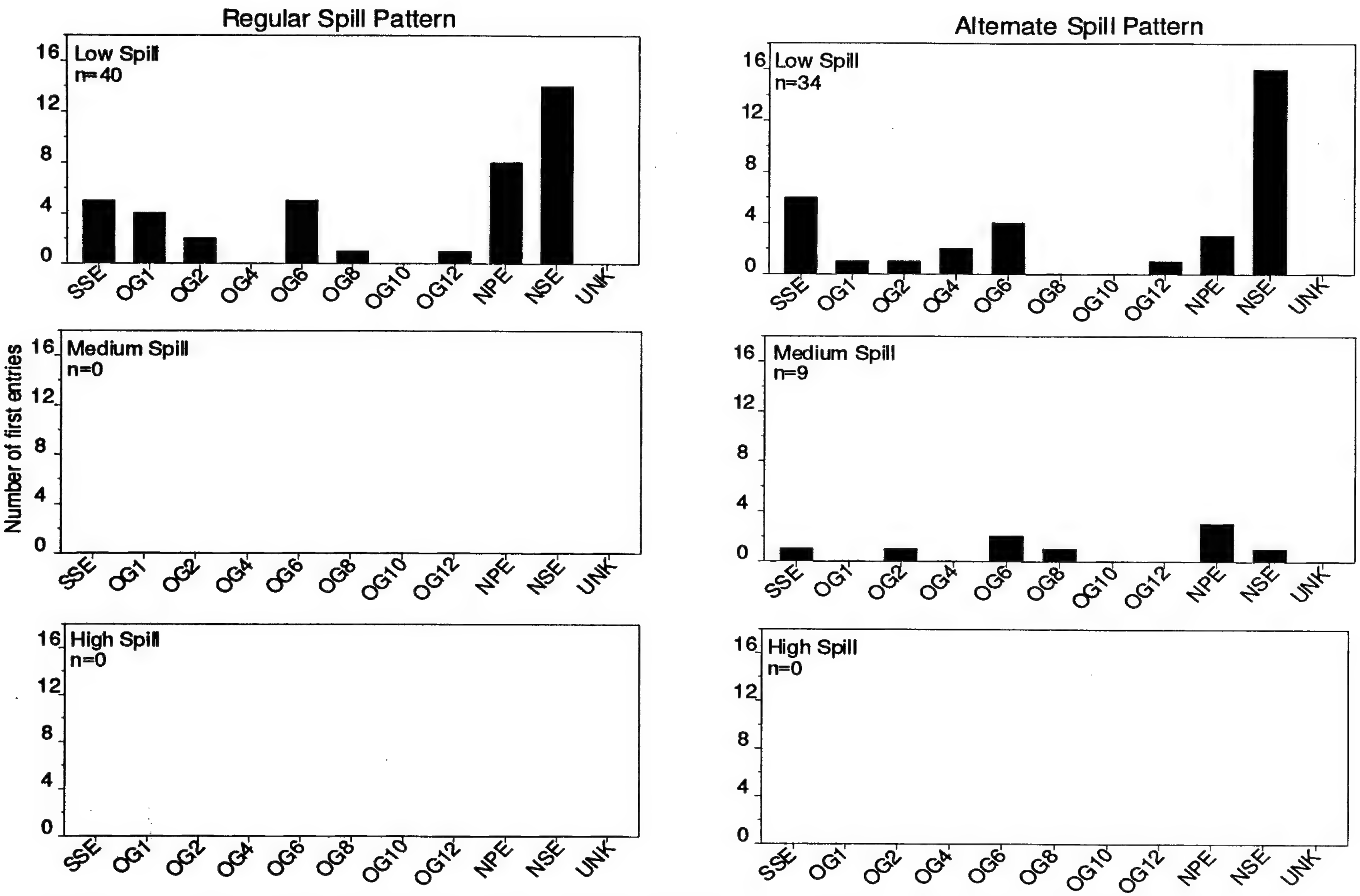


Figure 71. Fishway entrances used by chinook salmon exposed to only the regular or alternate spill patterns at Ice Harbor Dam during periods of low, medium , and high spill in the spring of 1993.

Lower Monumental Dam

Daytime spill began on 5 May 1993 and continued through 19 June with the exception of periods of no spill from 4 June at 2000 h to 7 June 1700 h, 16 June from 0100 h to 17 June 0600 h and intermittently on 18 and 19 June (Figure 72). Within the test period (14 May-19 June) there were 16.5 days of the regular spill pattern and 15 days of the alternate spill pattern (Figure 73). Maximum hourly average daytime spill was 106.0 kcfs recorded on 16 May at 1900 h. The period of highest daily average river discharge and highest daily average spill (15-23 May, Figure 52) generally coincided with fewer chinook salmon being recorded at the fishway counting windows as compared to the remainder of the spill season (Figure 72). However, the highest daily average spill (110.0 kcfs) was recorded on 16 May when 430 chinook salmon were counted at the window and 411 fish were counted on 15 May when the daily average spill was 69.0 kcfs.

At the lower levels of spill (< 40 kcfs), the regular and alternate spill patterns produced an area of surface turbulence that extended downstream about half the length of the south shore ladder (Figure 74; Appendix A, Figure A5). Most of the surface turbulence during the regular pattern was in the middle of the spillbasin and was rounded towards the edges as opposed to being flatter shaped during the alternate pattern. At medium spill levels, the surface turbulence extended downstream to between the end of the south shore ladder and the entrance to the lock (Figure 75; Appendix A; Figure A6). The shape of the turbulence during the regular pattern was flat at the downstream extent and tapered towards the north and south ends of the spill basin. The alternate pattern was more rounded than the regular pattern and the north side generally flowed straight downstream paralleling the lock, whereas the south edge tapered northward from the south shore ladder to the middle of the spill basin. The area in front of the entrance to the south shore ladder was turbulent during the regular pattern, but not during the alternate pattern. At high levels of spill, the surface turbulence from the spill discharge extended downstream to between the entrance to the lock and the downstream end of the guide wall (Figure 76; Appendix A, Figure A7). During both patterns, the area of surface turbulence extended straight downstream and the downstream end was flat shaped. The area in front of the entrance to the south shore ladder was turbulent during the regular pattern but not with the alternate pattern. At all levels of spill, boils of discharge water from the turbines being operated were obvious about 10 m downstream of the powerhouse. Currents in the tailrace generally flowed directly downstream during both spill patterns at low and medium levels of spill, however, an eddy formed along the south shore downstream of the lock guide wall at high spill levels during both spill patterns.

At low spill levels, 26 chinook salmon were available in the tailrace and made their first entry into the fishway, after being exposed to only the regular spill pattern, in a median of 2.8 h, compared to 3.1 h for fish (n = 24) entering during the alternate spill

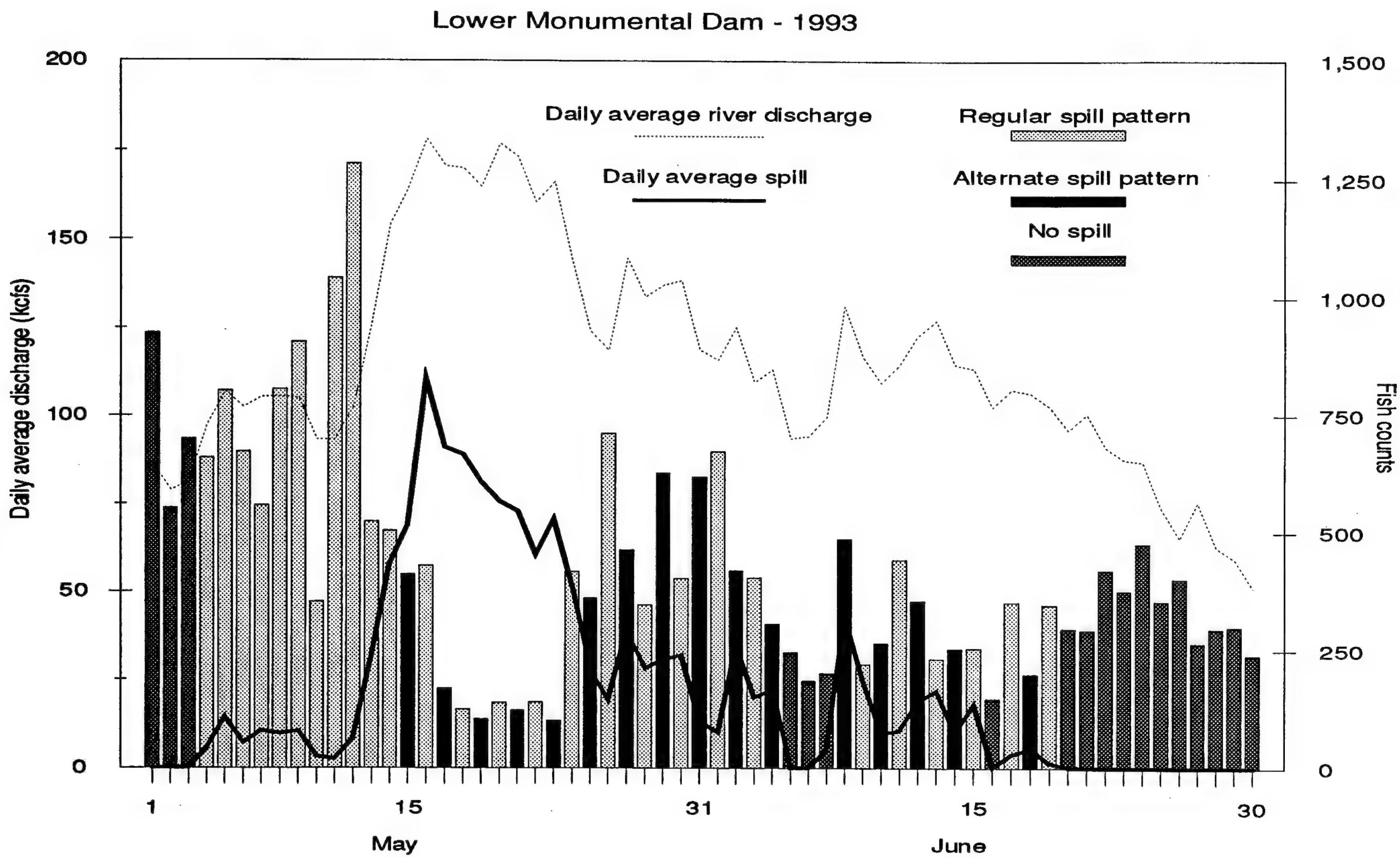


Figure 72. Daily average discharge and spill, and the number of chinook salmon observed at the north and south ladder counting windows (bars) at Lower Monumental Dam on days with regular or alternate spill patterns or no spill conditions from 1 May to 30 June 1993.

Figure 73. Duration of the regular and alternate spill patterns at Lower Monumental Dam in 1993.

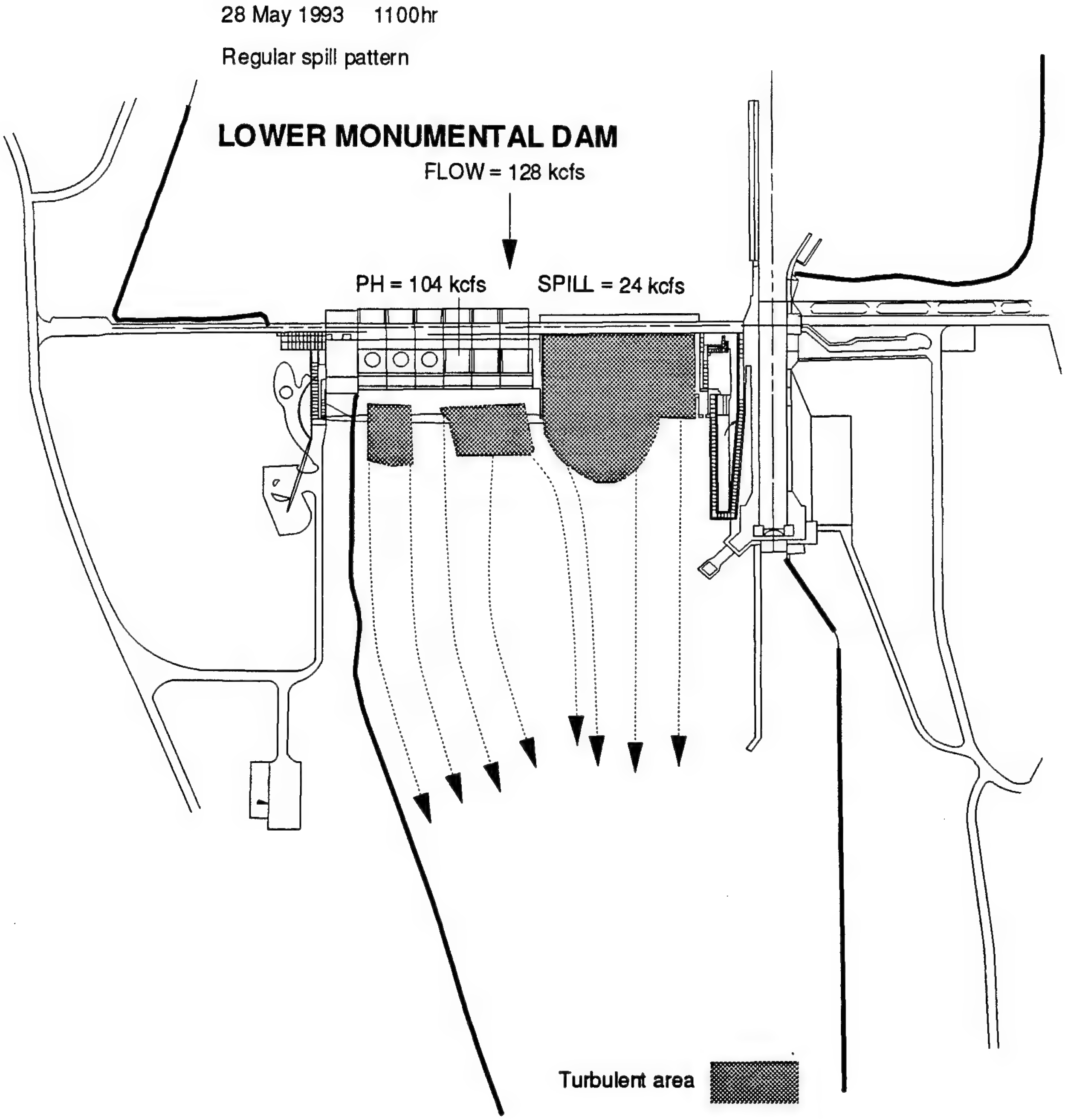


Figure 74. Flow patterns downstream from Lower Monumental Dam during the regular spill pattern at low spill levels (24 kcfs) as interpreted from video tape images and notes made at the time of spill in 1993.

pattern (Figure 77). There were an additional 30 fish that entered the fishway for the first time during the regular spill pattern at low levels of spill, after having been exposed to both spill patterns, and they took between 6.6 h and 3.8 days to enter. An additional 21 fish entered the fishway during the alternate spill pattern at low spill levels, that were

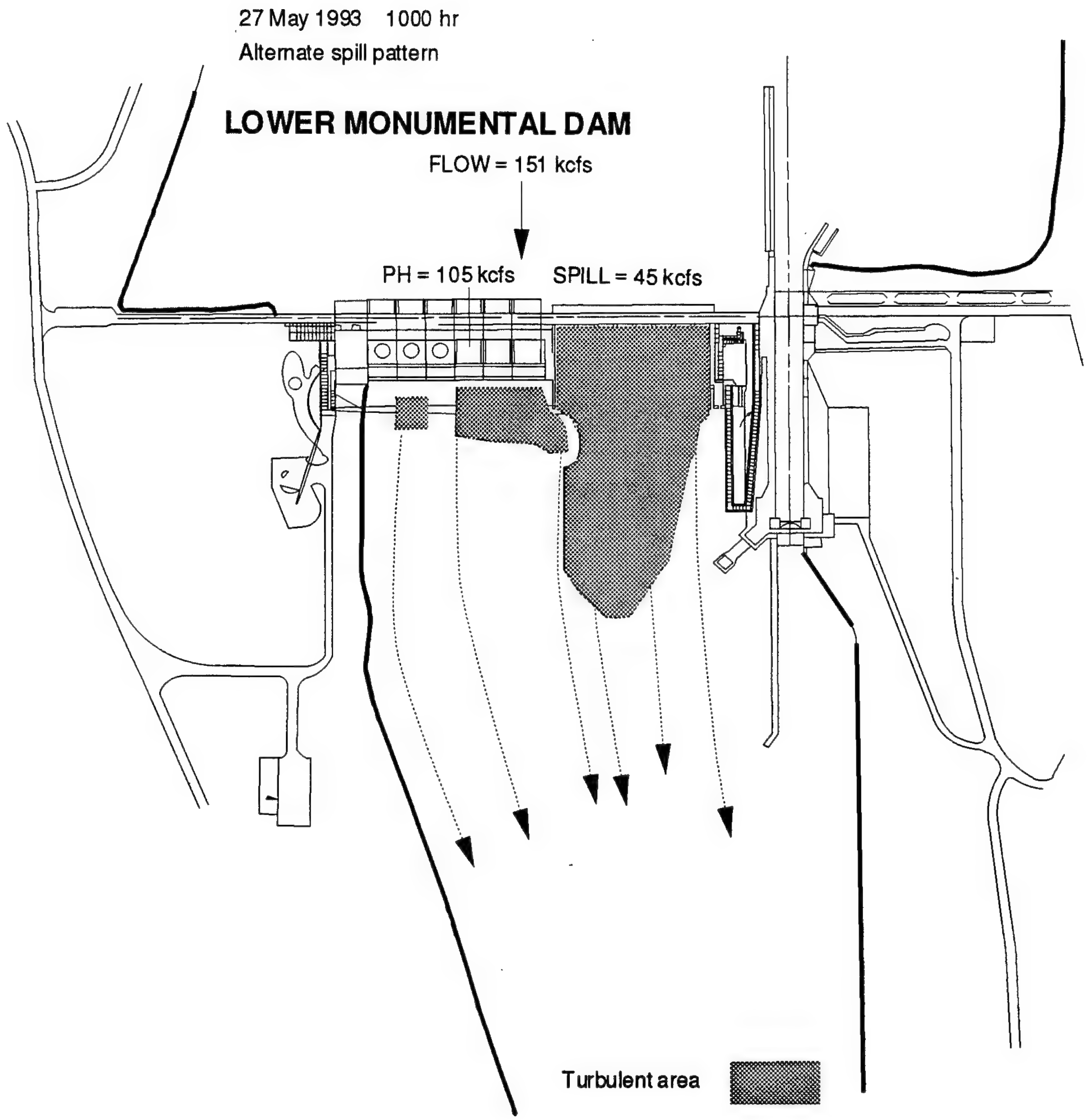


Figure 75. Flow patterns downstream from Lower Monumental Dam during the alternate spill pattern at medium spill levels (45 kcfs) as interpreted from video tape images and notes made at the time of spill in 1993.

exposed to both spill patterns, and they took between 10.5 h and 8.0 days to do so. At medium levels of spill, five fish took a median of 3.0 h to first enter the fishway after having been exposed to only the regular spill pattern, compared to 2.6 h (n = 12) for fish entering during the alternate pattern. Of the fish exposed to both spill patterns before

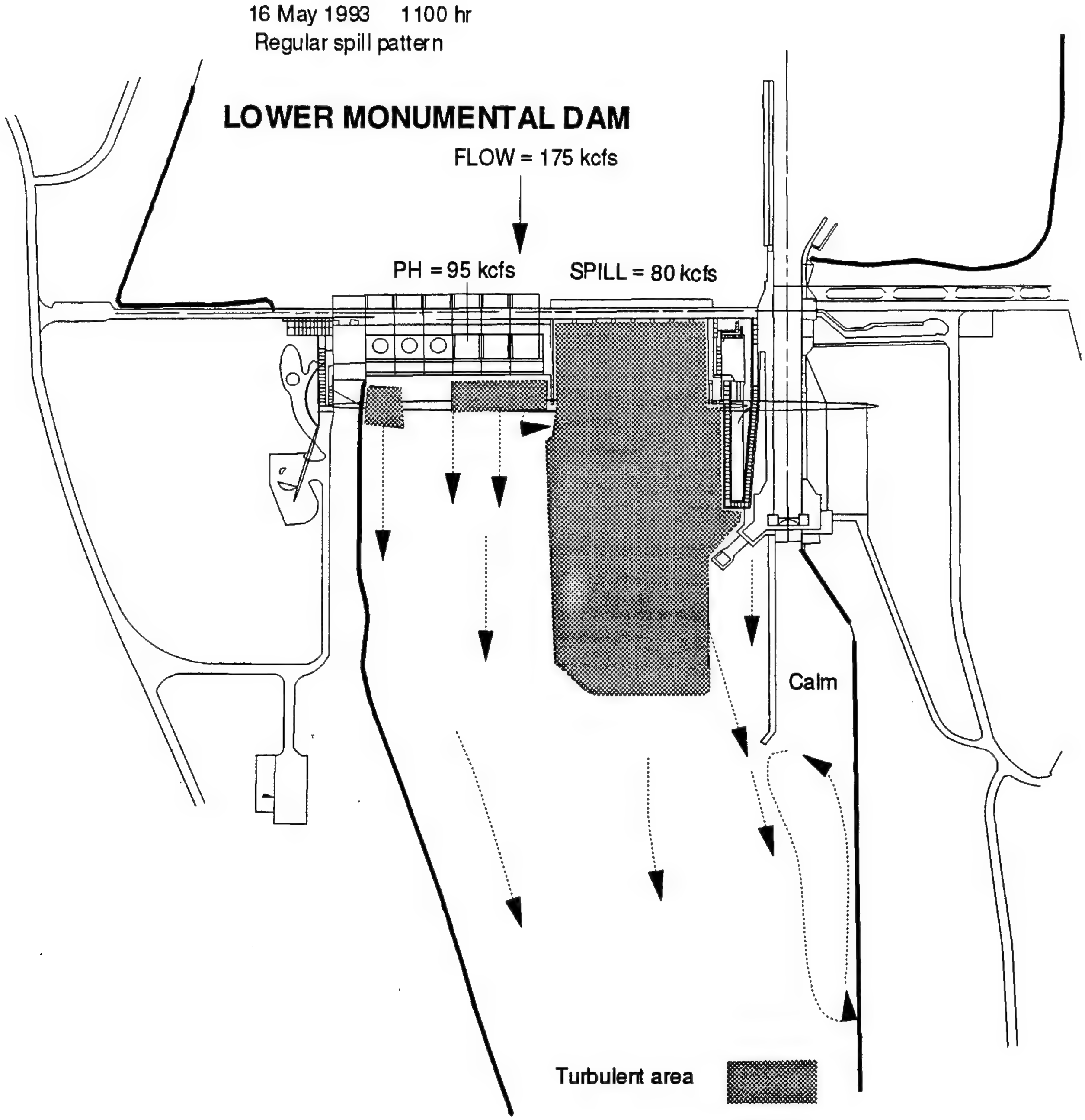


Figure 76. Flow patterns downstream from Lower Monumental Dam during the regular spill pattern at high spill levels (80 kcfs) as interpreted from video tape images and notes made at the time of spill in 1993.

entering the fishway, 12 entered during the regular spill pattern and took between 12.7 h and 4.9 days to enter, and an additional 12 fish that entered the fishway during the alternate spill pattern took between 7.9 h and 3.5 days to do so. There was one fish

recorded entering the fishway at high levels of spill during the regular spill pattern and it took almost two days to enter.

Chinook salmon that made their first entry into the fishway while exposed to only one spill pattern, used mostly the south and north shore entrances plus the south powerhouse entrances (Figure 78). During the regular spill pattern and at low levels of spill, 62% of the first entrances were at the south shore entrance, 15% at orifice gate 9 and 12% at the north shore entrance. During the alternate spill pattern, 42% of the first entrances occurred at the south shore entrance and 33.3% at the north shore entrance. All five fish entering the fishway during the regular spill pattern at medium levels of spill did so at the south shore entrance. During the alternate spill pattern, 50% made their first entries at south powerhouse entrances, 33.3% entered at the south shore entrance and the remainder entered at the north shore entrance.

Little Goose Dam

Daytime spill began on 1 May 1993 and continued through 19 June (Figure 79). There were periods of no spill on 31 May, 4 June 2200 h to 7 June 1700 h and 16 June from 0100 h to 17 June 2000 h and intermittently on 18 and 19 June (Figure 80). Within the test period (14 May to 19 June) there were a total of 16.2 days of the regular spill pattern and 15.5 days of the alternate spill pattern. Maximum hourly average daytime spill was of 106.3 kcfs recorded on 20 May at 1000 h. The period of highest daily average river discharge and highest daily average spill (15-24 May) generally coincided with fewer chinook salmon being recorded at the fishway counting window as compared to the remainder of the spill season (Figure 79).

At the lower levels of spill, the regular pattern produced two plumes of surface turbulence from either end of the spillbasin and extended just downstream of the north shore entrance (Figure 81). The spillbasin discharge from the alternate spill pattern produced a tiered area of surface turbulence with the first tier downstream from spillbays 1 and 2, and 6-8 and the second tier extending twice the distance downstream of the first tier and downstream of spillbays 3-5 (Appendix A; Figure A8 and A9). A large eddy formed in the cul-de-sac area along the north shore during both spill patterns. At medium spill levels, the surface turbulence extended downstream at least as far as the entrance to the lock during both spill patterns (Figure 82, Appendix A; Figure A10). Surface turbulence during the regular pattern (38 kcfs) was slightly tapered towards the north shore at the downstream extent with the majority of the surface turbulence downstream of the southern most spillbays. The downstream extent of the surface turbulence during the alternate spill pattern was more rounded than the regular pattern and generally flowed straight downstream. The area in front of the entrance to the north shore ladder was turbulent during both spill patterns. The eddy in the cul-de-sac was present during both spill patterns in addition to an eddy formed during the alternate pattern (70 kcfs) between the powerhouse and the peninsula where the juvenile fish

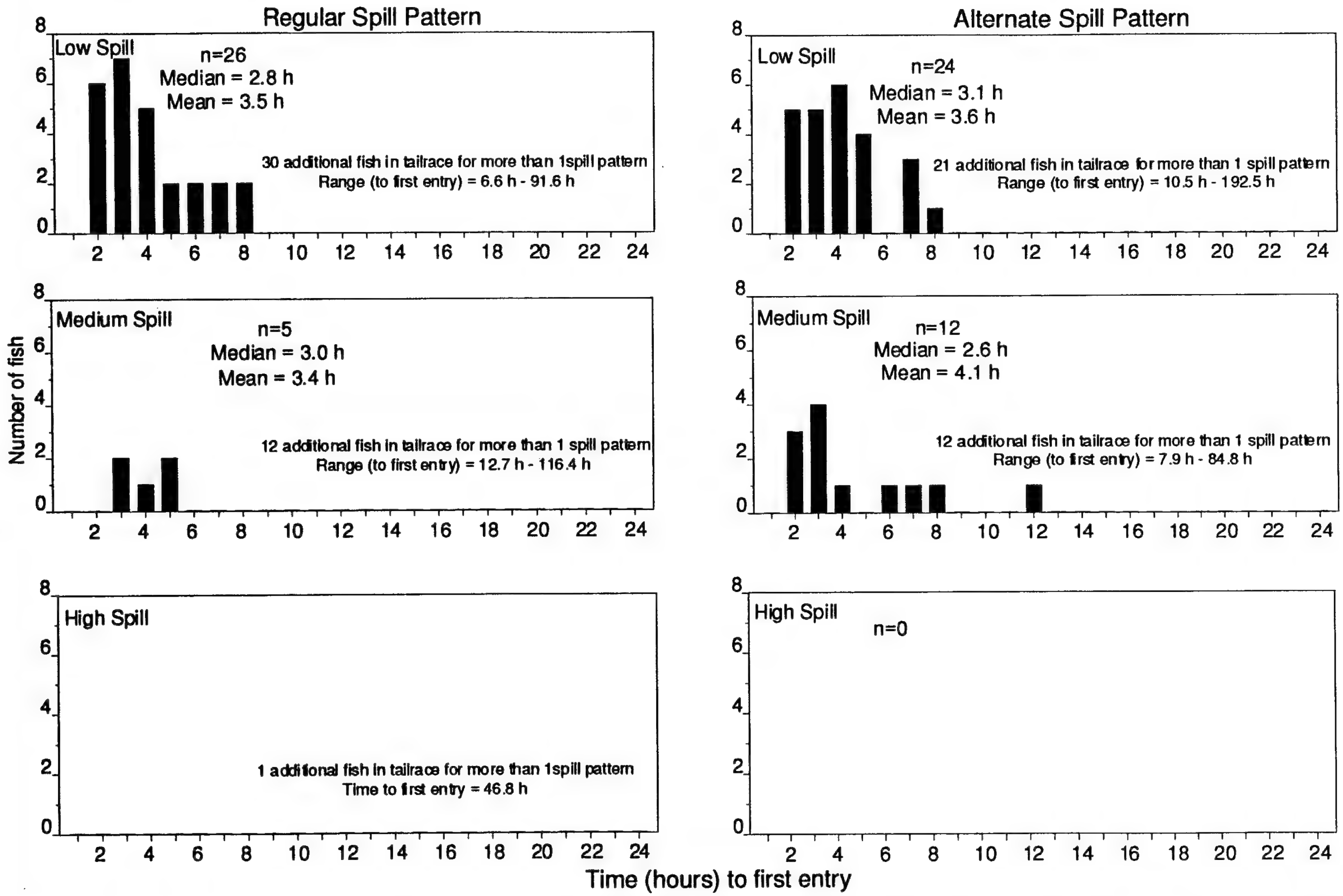


Figure 77. The number of chinook salmon and the elapsed time from their entry into the tailrace to first entrance into the fishways at Lower Monumental Dam during regular and alternate spill patterns at low, medium and high spill levels in 1993.

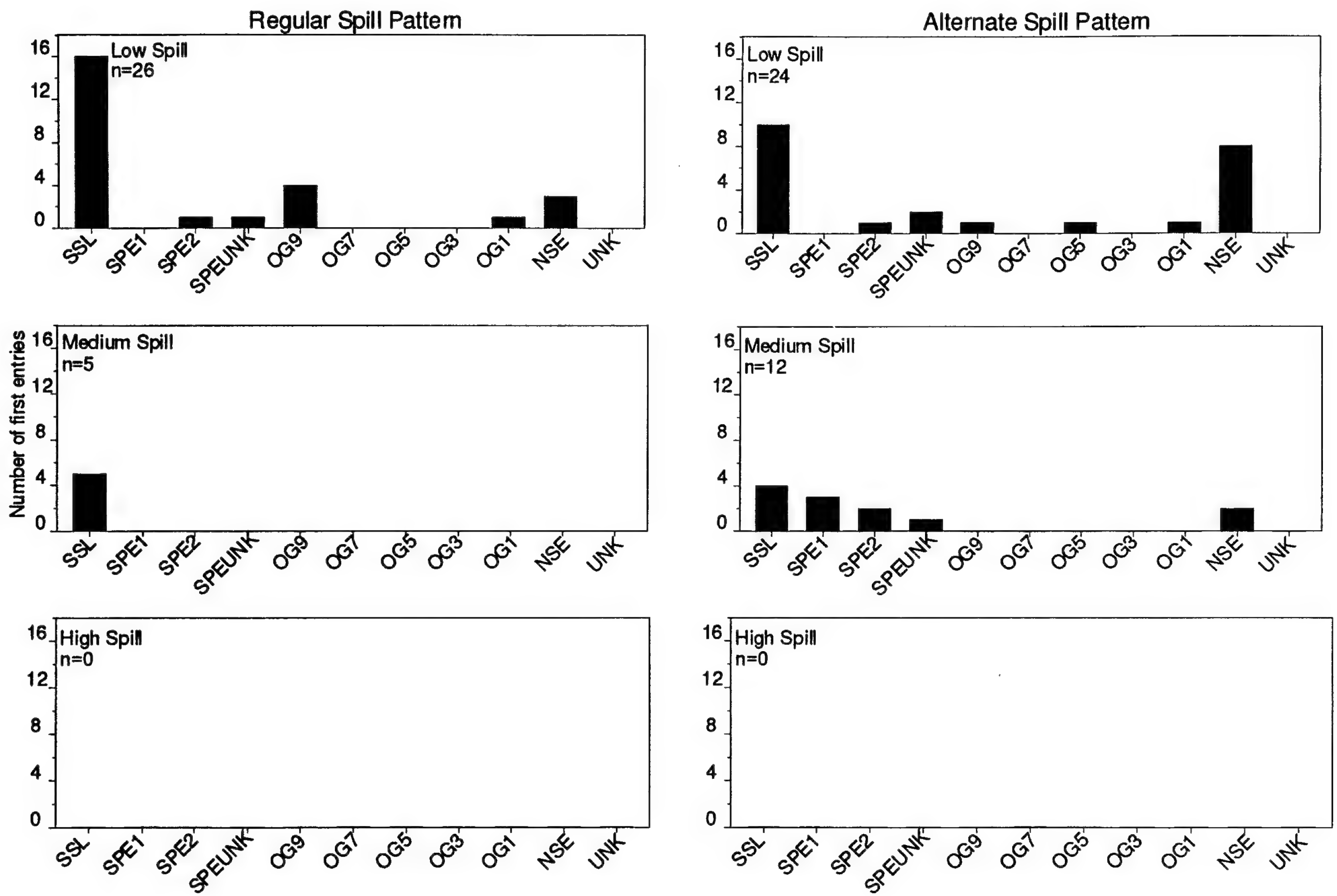


Figure 78. Entrances used by chinook salmon that made their first entry into the Lower Monumental Dam fishways after having been exposed to only one spill pattern and level of spill in 1993.

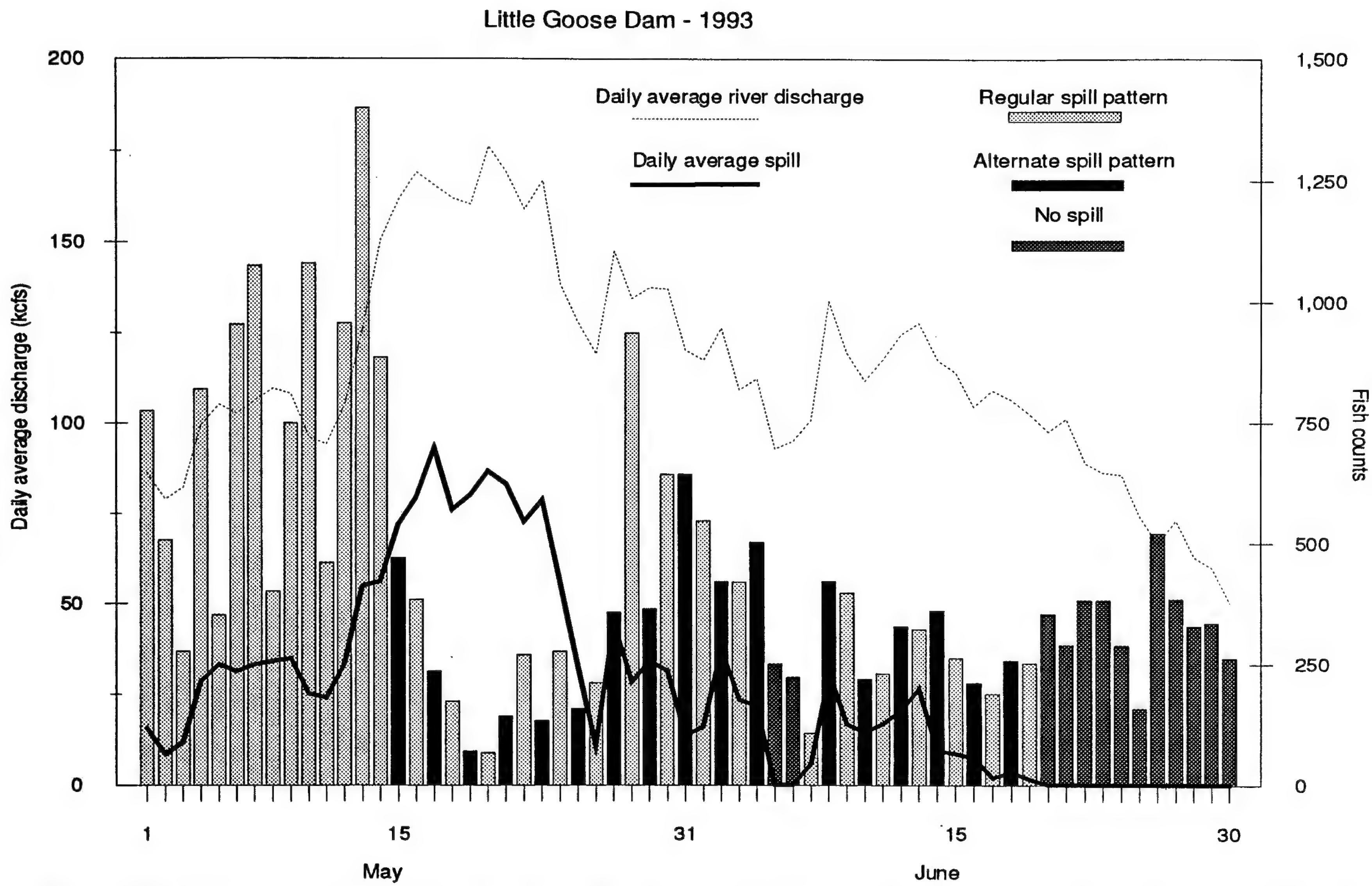


Figure 79. Daily average discharge and spill, and the number of chinook salmon observed at the south ladder counting window (bars) at Llittle Goose Dam on days with regular or alternate spill patterns or no spill conditions from 1 May to 30 June 1993.

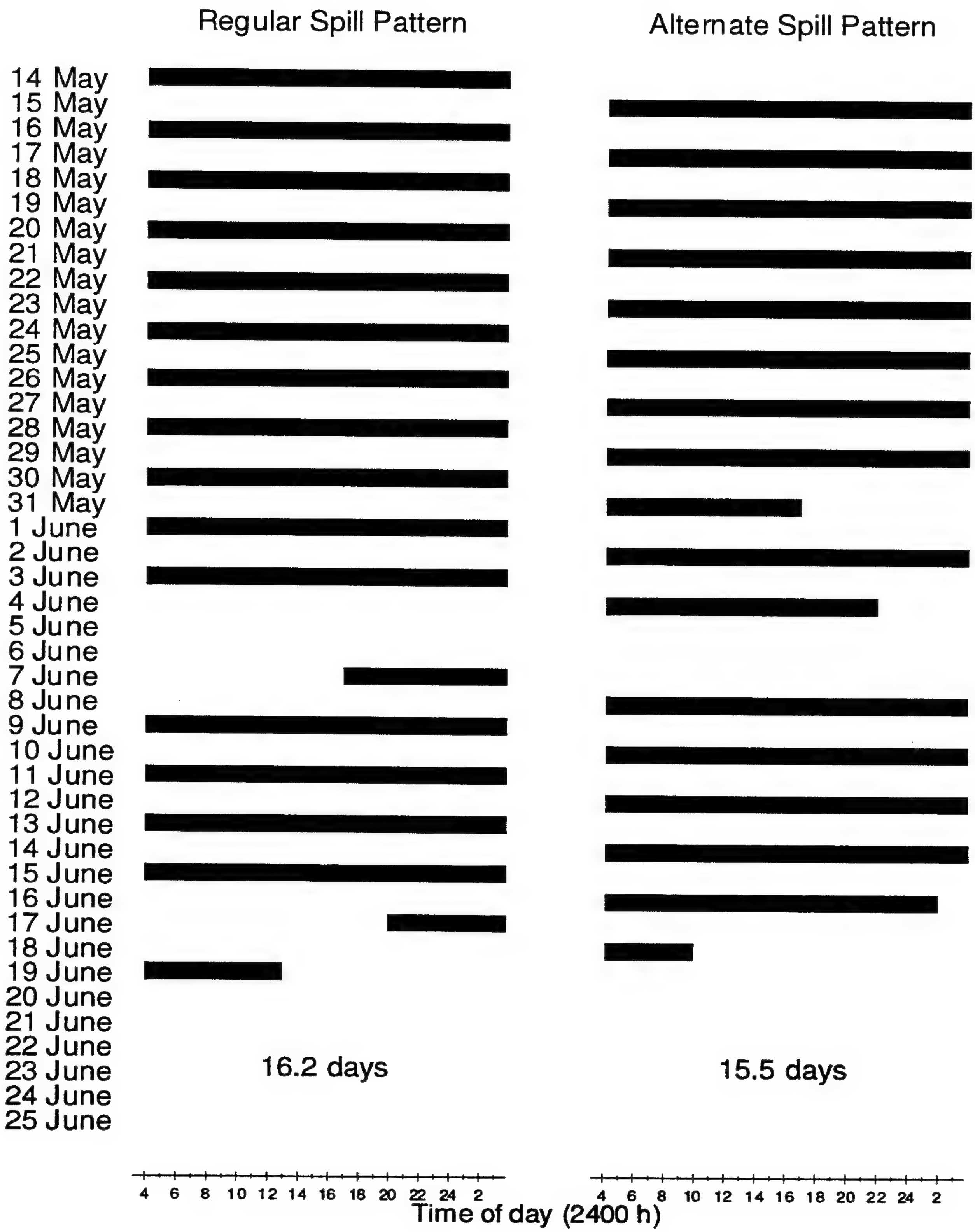


Figure 80. Duration of the regular and alternate spill patterns at Little Goose Dam in 1993.

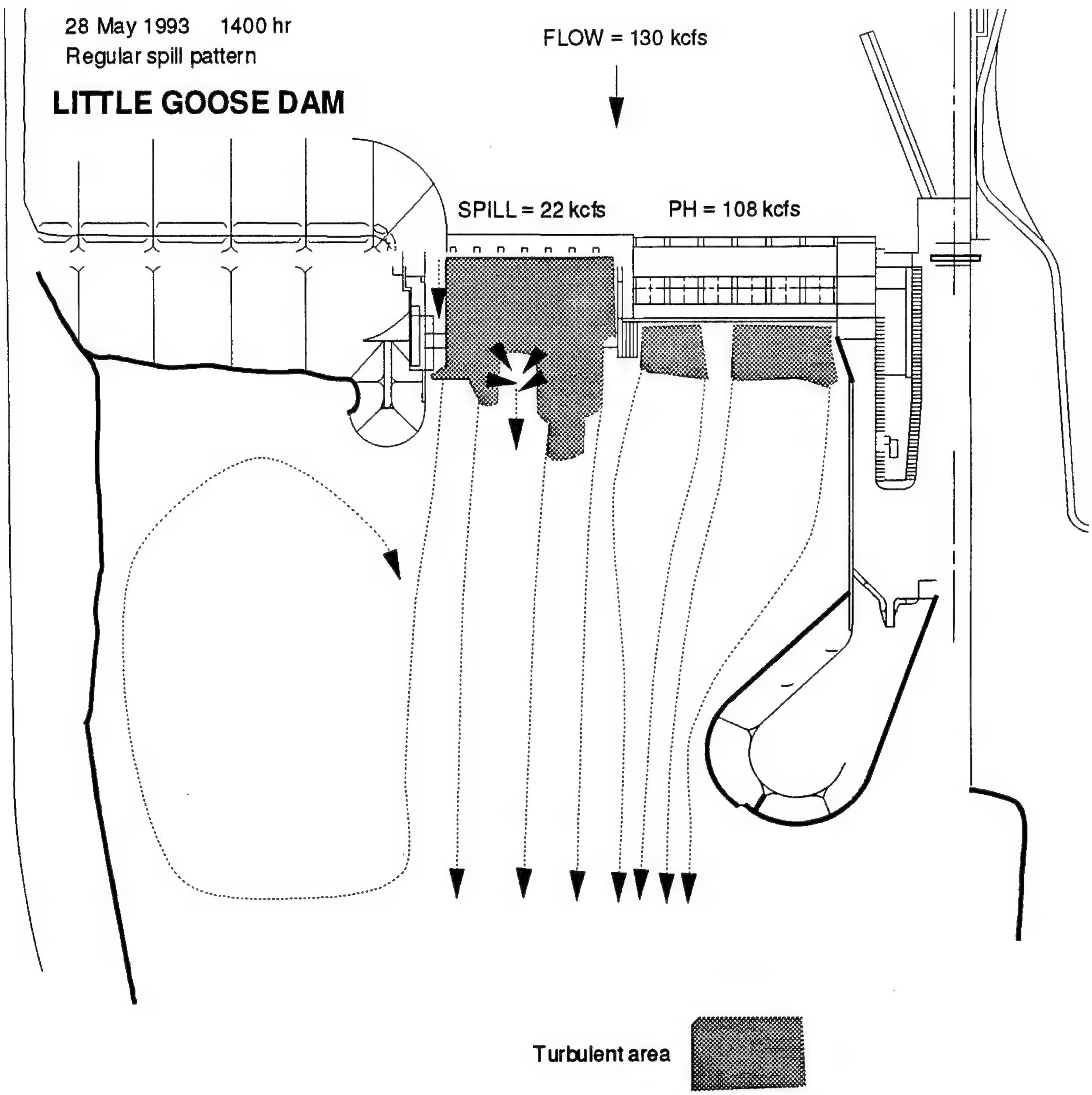


Figure 81. The regular spill pattern at Little Goose Dam during a low spill level (22 kcfs) as interpreted from video tape images and notes made at the time.

facility is sited (Appendix A; Figure A11). At high levels of spill, the surface turbulence from both spill patterns extended downstream to between the entrance to the lock and the tip of the peninsula (Figure 83, Appendix A; Figure A12). During both patterns, the area of surface turbulence flowed straight downstream from the spillbays and the area in front of the north shore entrance was turbulent. The downstream extent of turbulent area was flat shaped during the regular pattern although the tip angled slightly from south

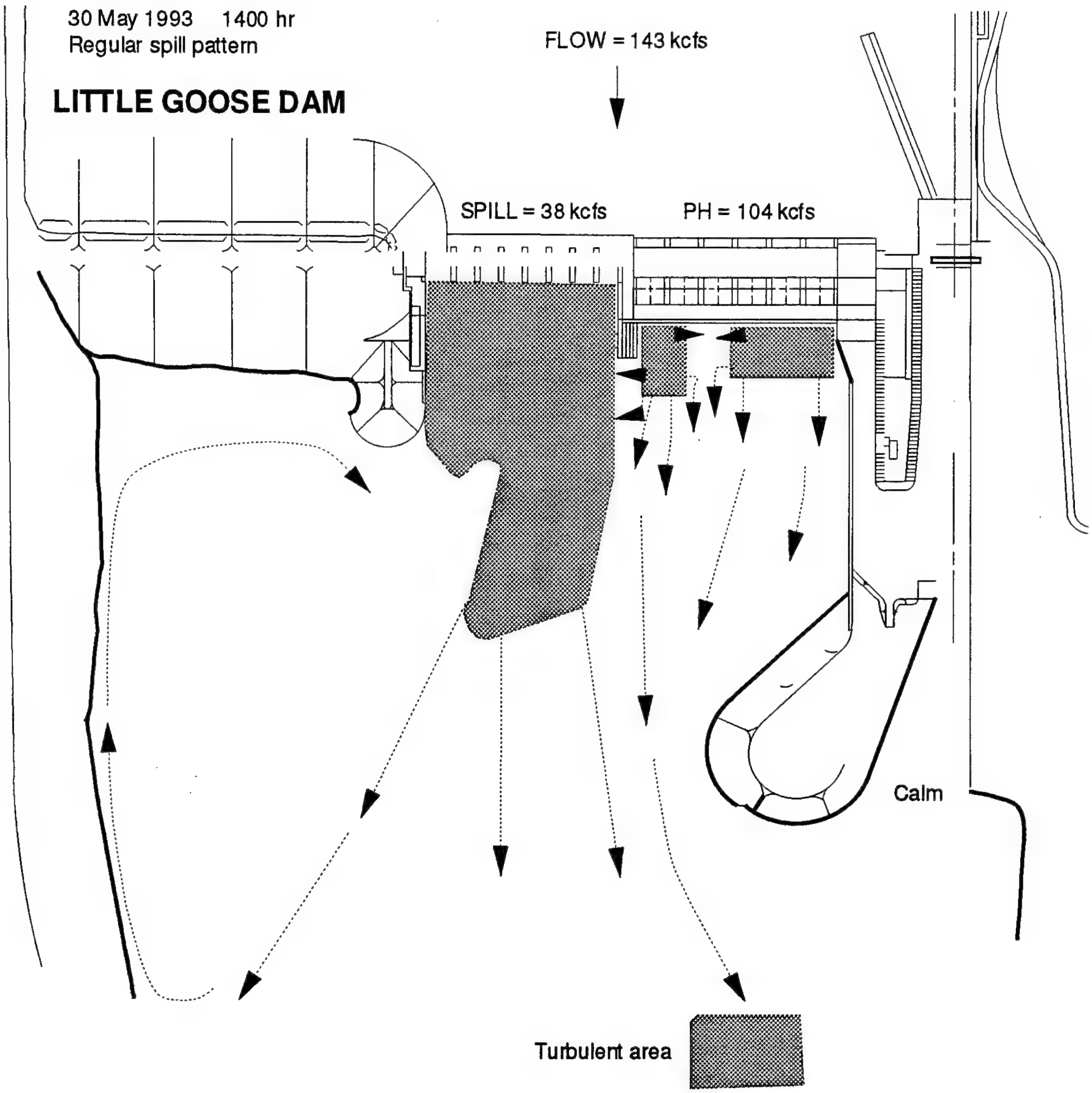


Figure 82. The regular spill pattern at Little Goose Dam during a medium spill level (38 kcfs) as interpreted from video tape images and notes made at the time.

to north. However, during the alternate pattern the surface turbulence extended furthest downstream of spillbays 1-5, the least distance downstream of bays 6 and 7 and an intermediate distance downstream of spillbay 8. Eddies were observed in the cul-de-sac and in front of the powerhouse during both spill patterns. Spilled water intersected the peninsula and flowed back upstream following the south shoreline towards the powerhouse until meeting the turbine discharge which wassufficient to turn the current north towards the north shore and spillway discharge. At all levels of spill, boils of discharge water from turbines being operated were obvious about 10 m downstream.

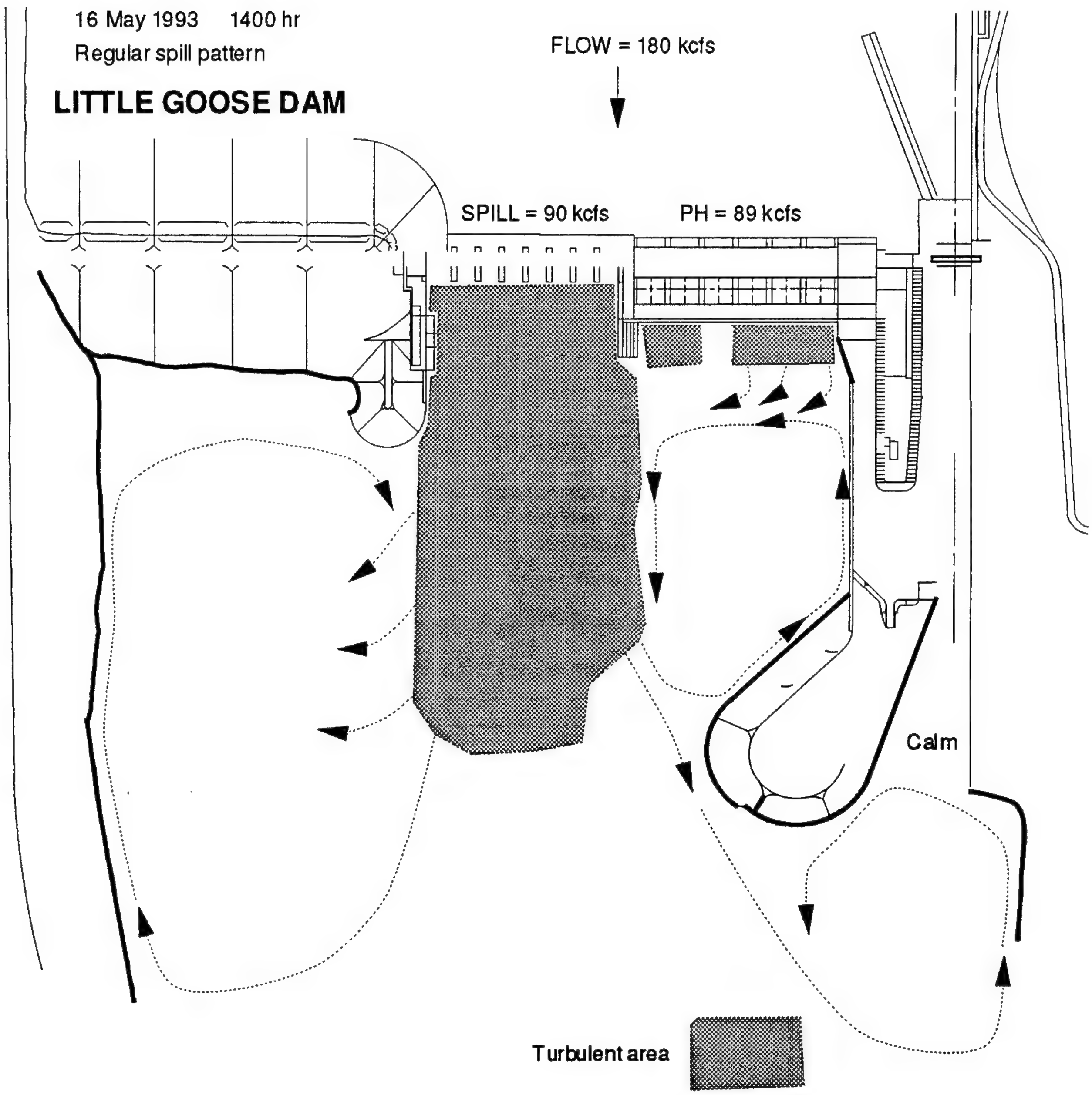


Figure 83. The regular spill pattern at Little Goose Dam during a high spill level (90 kcfs) as interpreted from video tape images and notes made at the time.

At low spill levels, 34 chinook salmon were available in the tailrace and made their first entry into the fishway while exposed to only the regular spill pattern, and took a median of 2.8 h to enter the fishway compared to 2.3 h for fish (n = 22) entering during the alternate spill pattern (Figure 84). There were an additional 47 fish that entered the fishway for the first time during the regular spill pattern at low levels of spill after having been exposed to both spill patterns and they took between 2.5 h and 8.7 days to enter, with an additional 17 fish entering the fishway during the alternate spill pattern at low spill levels and they took between 4.6 h and 6.3 days to do so. At medium levels of spill, 12

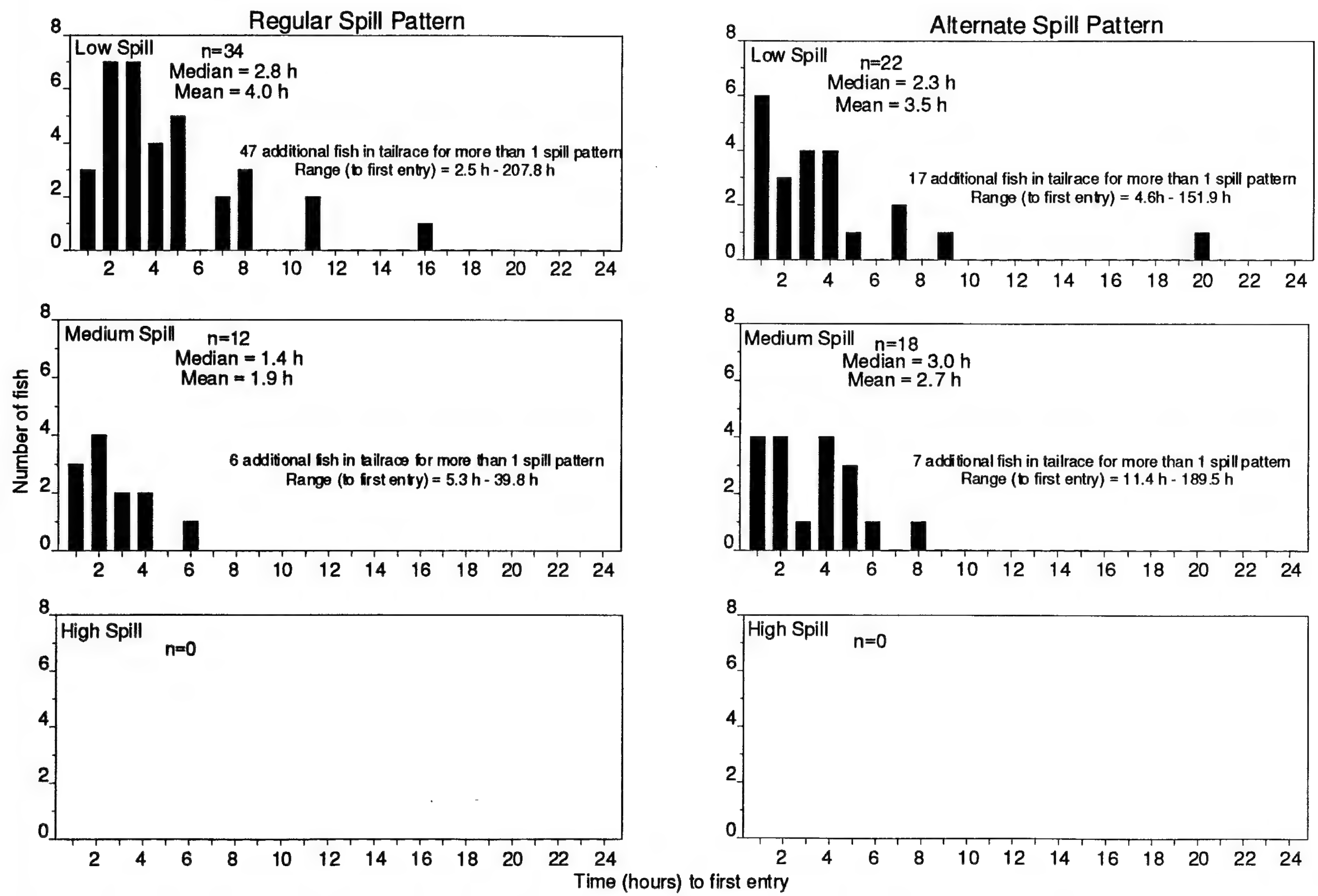


Figure 84. The number of chinook salmon and the elapsed time from their entry into the tailrace to first entrance into the fishway at Little Goose Dam during regular and alternate spill patterns at low, medium and high spill levels in 1993.

fish exposed to only the regular spill pattern took a median of 1.4 h to first enter the fishway compared to 3.0 h (n = 18) for fish entering during the alternate pattern. Of the fish exposed to both spill patterns before entering the fishway, six entered the fishway during the regular spill pattern and took between 5.3 h and 1.7 days, with an additional seven fish that entered the fishway during the alternate spill pattern and took between 11.4 h and 7.9 days to do so. There were no fish recorded entering the fishway at high levels of spill during the regular or alternate spill pattern.

Chinook salmon that made their first entry into the fishway while exposed to only one spill pattern, used mostly the south and north shore entrances plus the north powerhouse entrances (Figure 85). During the regular spill pattern and at low levels of spill, 65% of the first entrances were in either south shore entrance or orifice gate 1, 29% at the north shore entrance and 6% at north powerhouse entrances 1 and 2. During the alternate spill pattern, 64% of the first entrances occurred at the north shore entrance and 32% at the south shore entrance. During the regular spill pattern at medium levels of spill, 42% of the fish first entered the fishway via the north shore entrance and 33% in the south shore entrance. During the alternate spill pattern, 78% made their first entries at the north shore entrance and the remainder entered either south shore entrance or orifice gate 1.

Lower Granite Dam

Daytime spill began on 13 May 1993 and continued through 8 June (Figure 86). There were intermittent periods of no spill on 25-26 May, and from 30 May to 8 June (Figure 87). Within the test period (14 May-8 June) there were a total of 9.2 days of the regular spill pattern and 8.8 days of the alternate spill pattern. There were no days of high daytime spill (>80 kcfs) during the test period. Maximum hourly average daytime spill was of 78.0 kcfs recorded on 16 May at 1600 h. The period of highest daily average river discharge and highest daily average spill (16-22 May, Figure 54) generally coincided with fewer chinook salmon being recorded at the counting window of the fishway as compared to the remainder of the spill season (Figure 86).

At the lower levels of spill (15 kcfs), the regular pattern produced two plumes of surface turbulence from either end of the spillway and extended downstream about half the length of the lock (Figure 88). Between the two plumes the currents flowed toward the middle of the spill basin in front of bays 4 and 5 and then downstream. An eddy formed along the north shoreline in front of the cul-de-sac. We were unable to record the alternate pattern at low levels of spill. At medium spill levels (52 kcfs), the surface turbulence extended downstream at least as far as the entrance to the lock (Figure 89; Appendix A, Figure A13). We were unable to video tape the regular pattern in the 40-50 kcfs range of spill. Surface turbulence during the alternate pattern generally flowed straight downstream to about the entrance to the lock. The majority of the turbulence

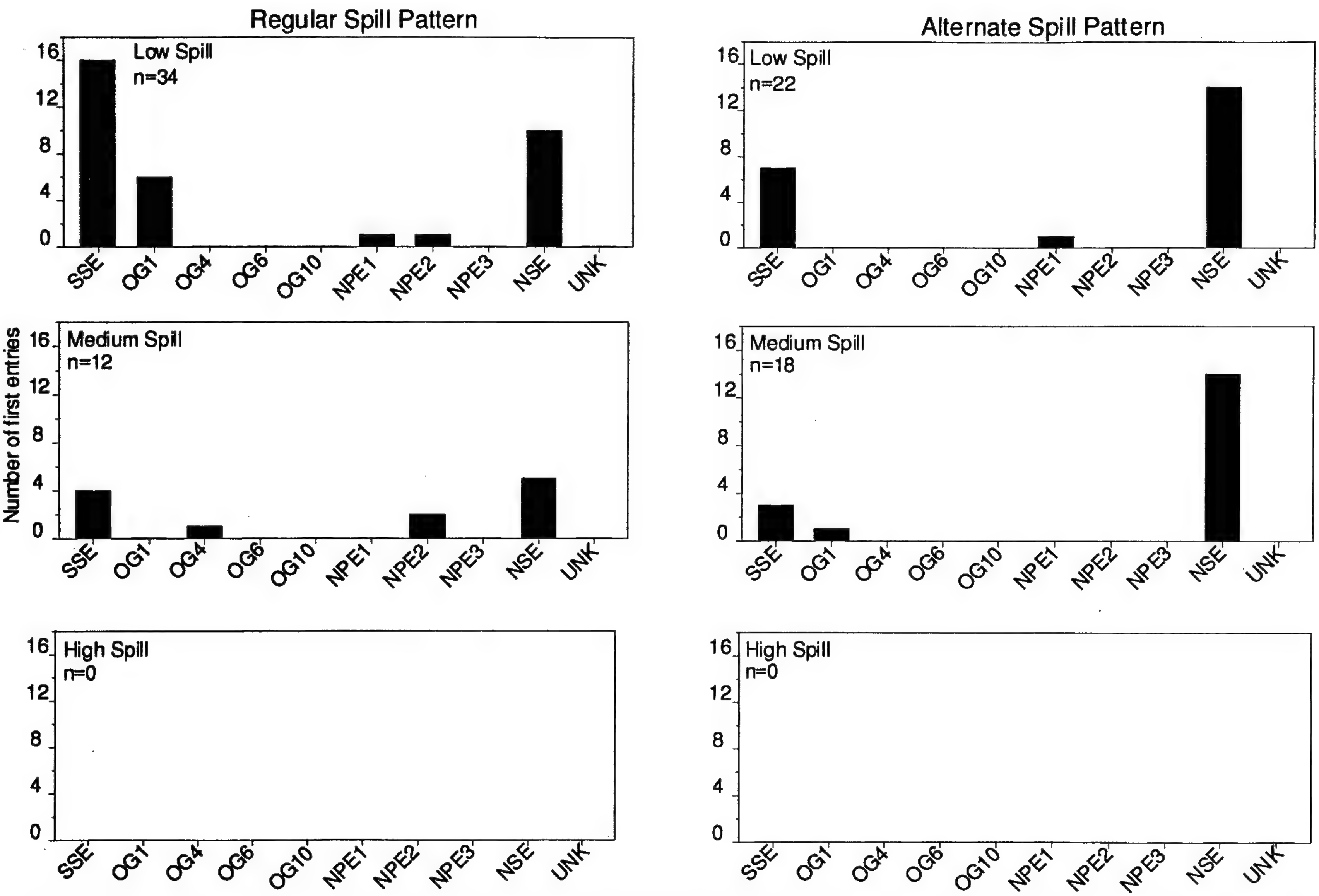


Figure 85. Entrances used by chinook salmon that made their first entry into the Little Goose Dam fishway after having been exposed to only one spill pattern and level of spill in 1993.

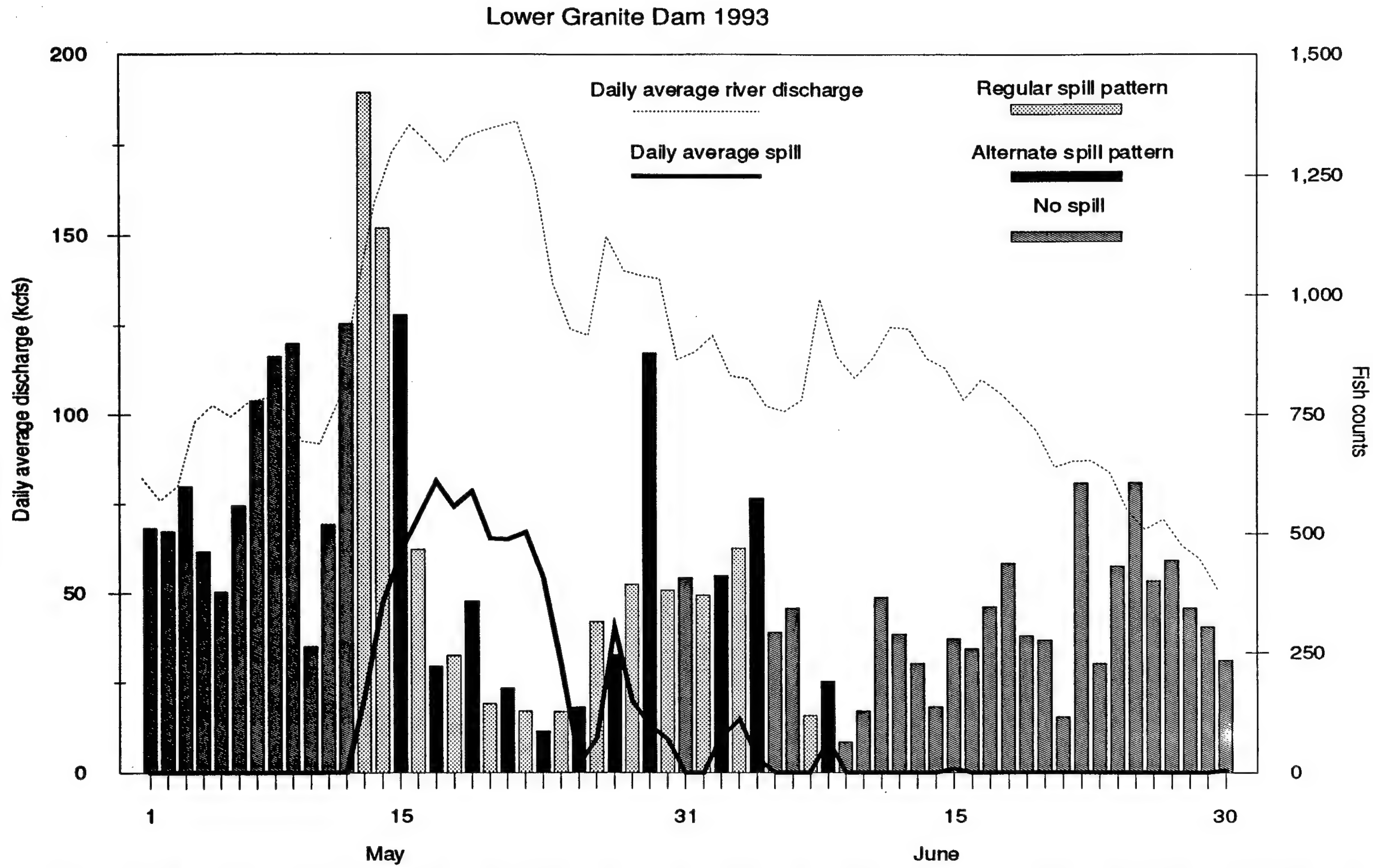


Figure 86. Daily average discharge and spill, and the number of chinook salmon observed at the south ladder counting window (bars) at Lower Granite Dam on days with regular or alternate spill patterns or no spill conditions from 1 May to 30 June 1993.

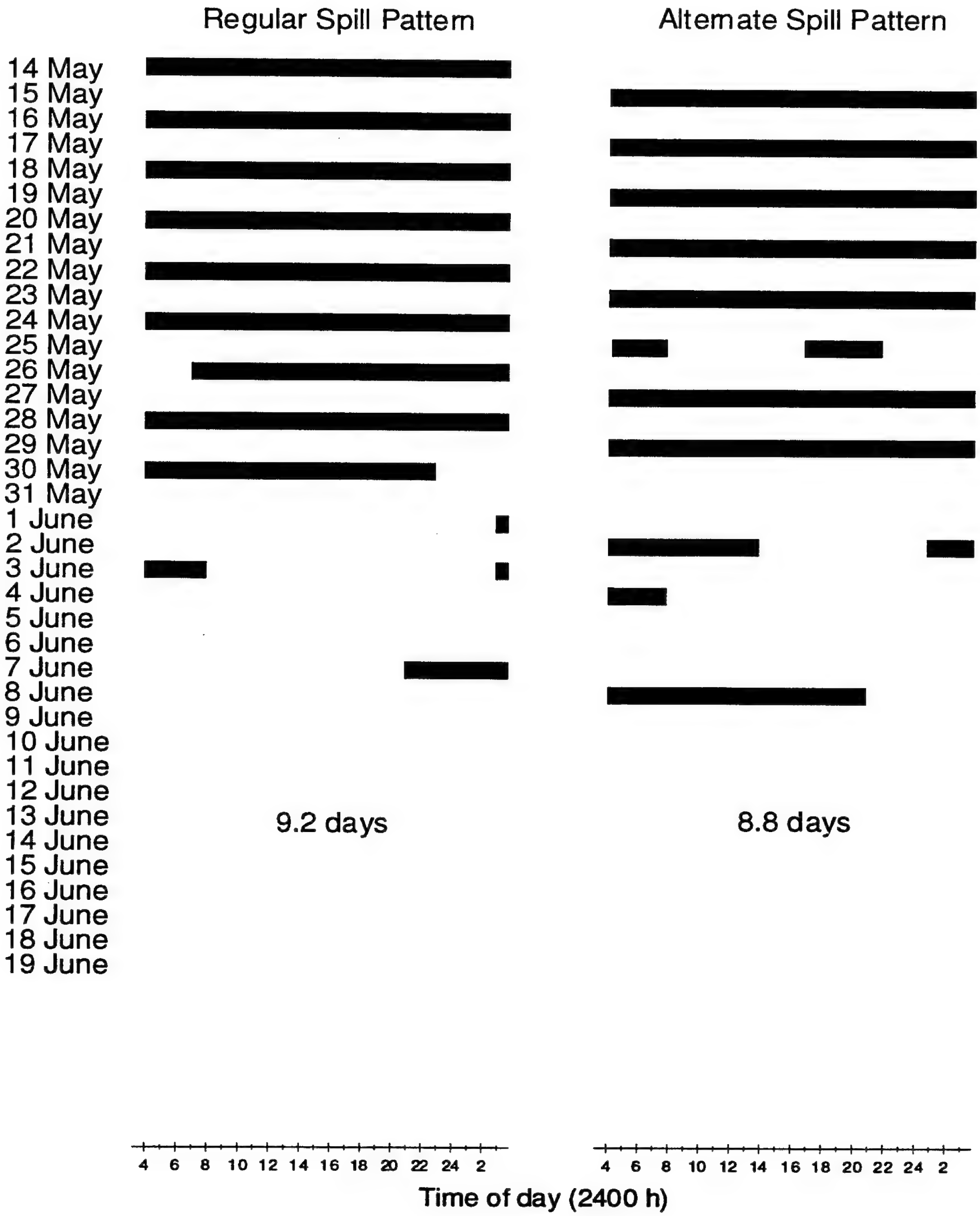


Figure 87. Duration of the regular and alternate spill patterns at Lower Granite Dam in 1993.

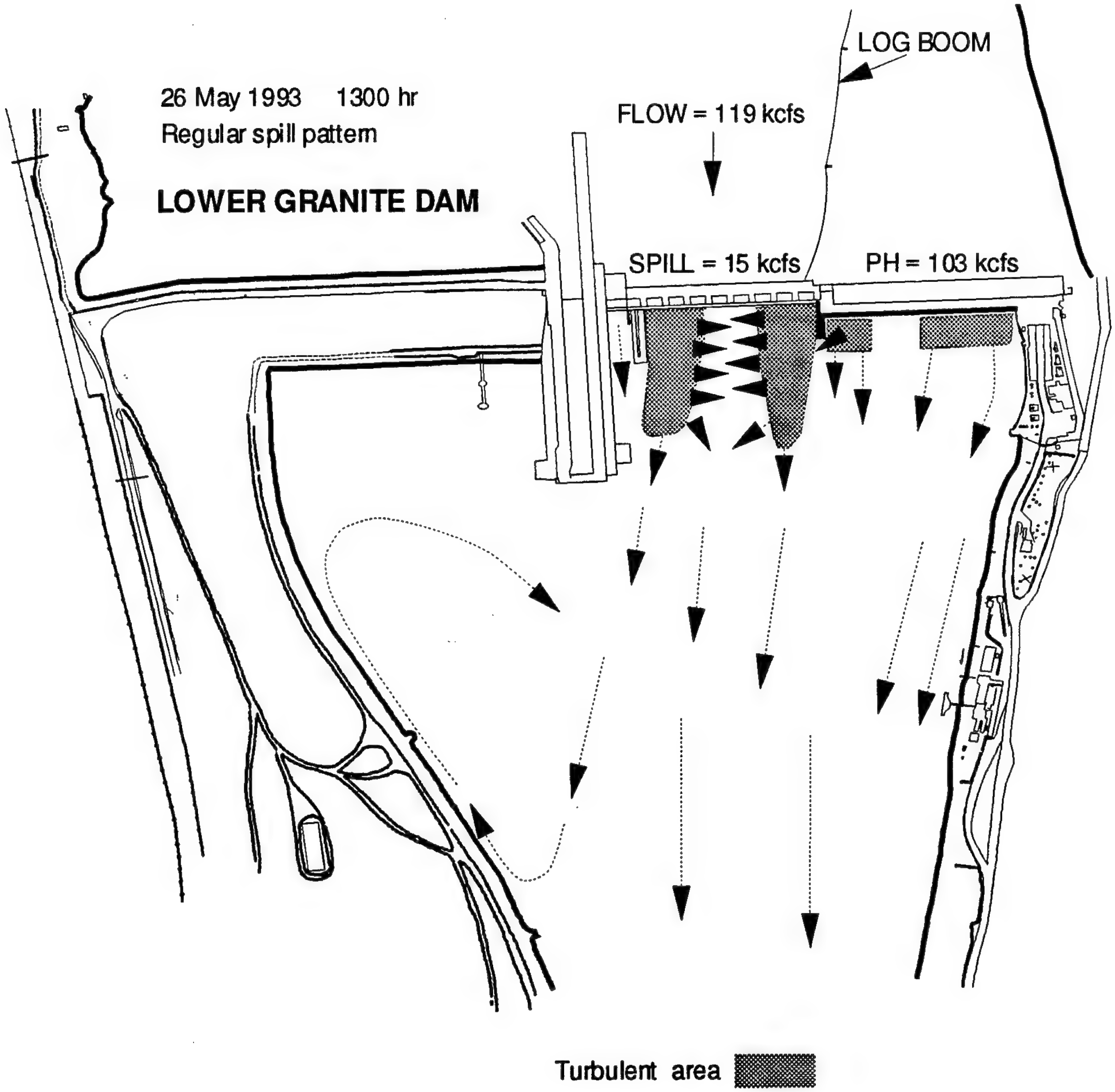


Figure 88. The regular spill pattern at Lower Granite Dam during a low spill level (15 kcfs) as interpreted from video tape images and notes made at the time.

was downstream from the southern most spillbays and tapered towards the northern spillbays. At upper levels of observed spill (65-70 kcfs), the surface turbulence from both spill patterns extended further downstream than during the lower levels of spill and both patterns appeared to be shaped similar to the alternate pattern at lower levels of spill (Figure 90; Appendix A, Figure A14). In addition to the eddy observed in the cul-de-sac, smaller eddies were observed along the south shore from the juvenile fish transportation facility upstream towards the powerhouse during both spill patterns when approximately

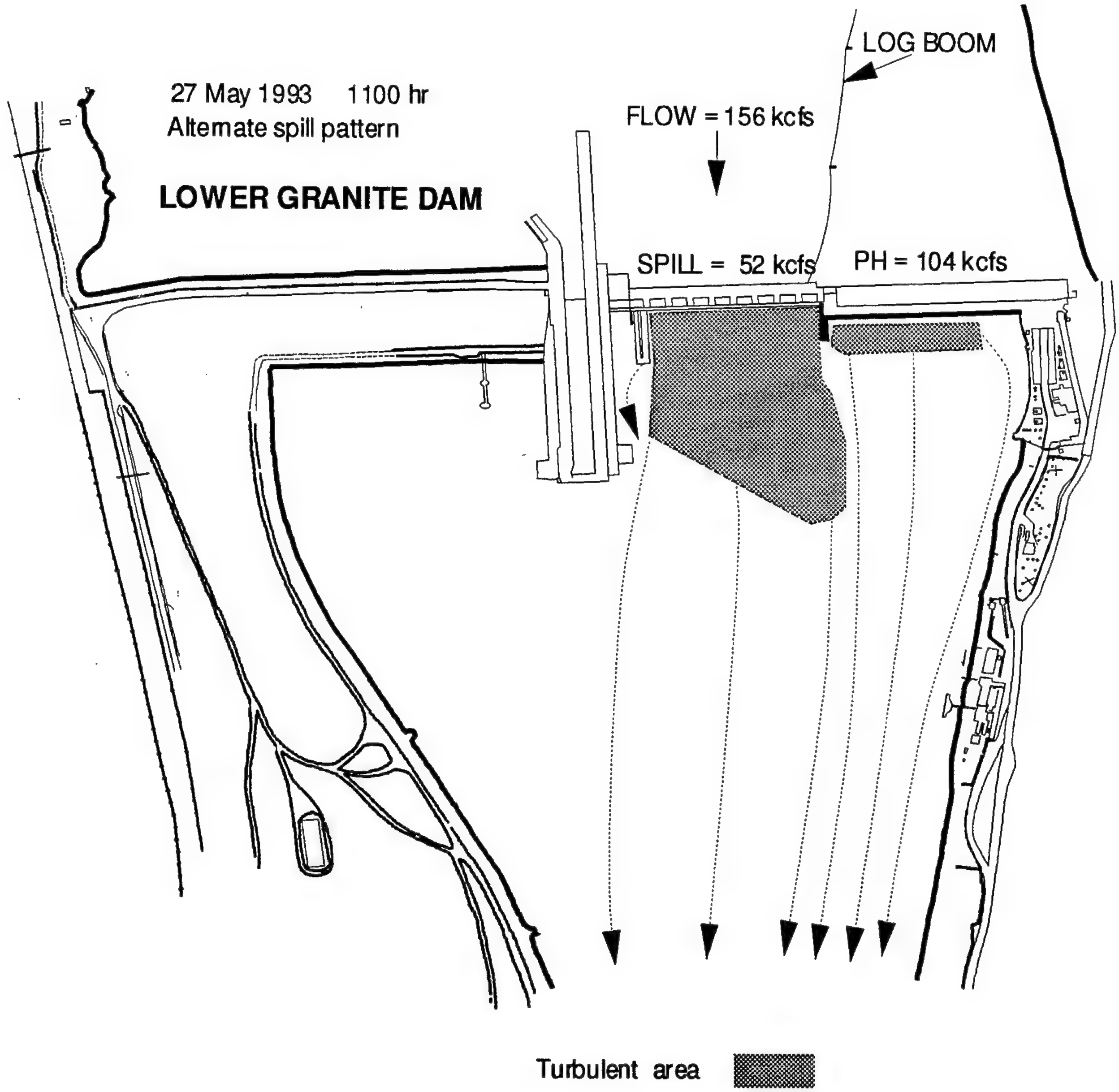


Figure 89. The alternate spill pattern at Lower Granite Dam during medium spill levels (52 kcfs) as interpreted from video tape images and notes made at the time.

110 kcfs was released from the powerhouse. An eddy did not form along the south shore at higher spills when powerhouse discharge was 127 kcfs (Appendix A; Figure A15). At all levels of spill, boils of turbine discharge water from operating turbines were obvious about 10 m downstream of the powerhouse.

At low spill levels, 17 chinook salmon were available in the tailrace and made their first entry into the fishway, while exposed to only the regular spill pattern, and took a median of 2.4 h to do so, compared to 2.5 h for fish (n = 14) entering during the alternate

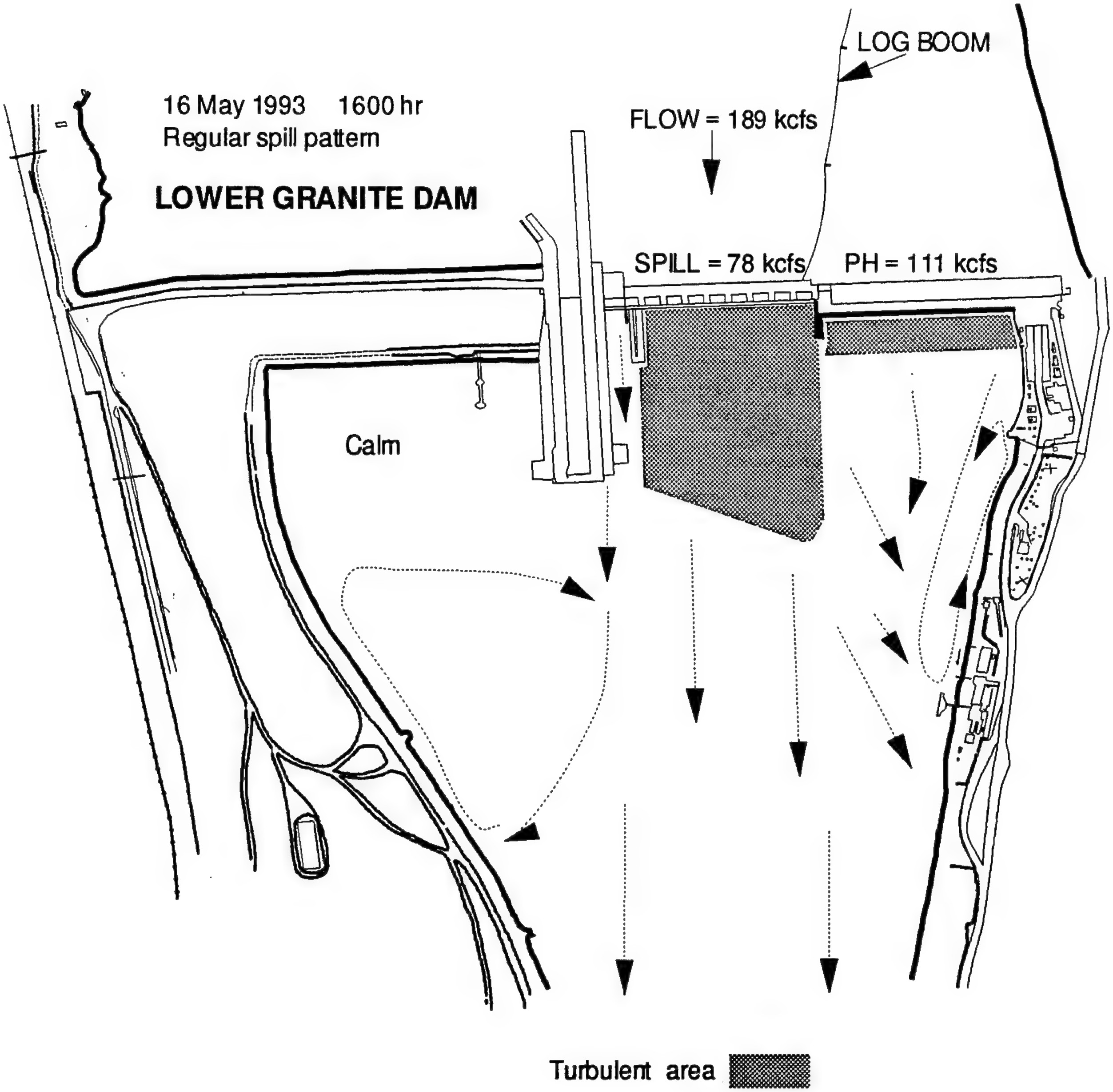


Figure 90. The regular spill pattern at Lower Granite Dam during a high spill level (78 kcfs) as interpreted from video tape images and notes made at the time.

spill pattern (Figure 91). There were an additional 10 fish that entered the fishway for the first time during the regular spill pattern at low levels of spill after having been exposed to both spill patterns and they took between 2.9 h and 1.4 days to enter, and an additional eight fish entered the fishway during the alternate spill pattern at low spill levels and they took between 2.2 h and 1.7 days to do so. At medium levels of spill, 13 fish exposed to only the regular spill pattern took a median of 1.9 h to first enter the fishway compared to 3.3 h for fish (n = 14) entering during the alternate pattern. Of the fish exposed to both spill patterns before entering the fishway, three entered the fishway during the regular

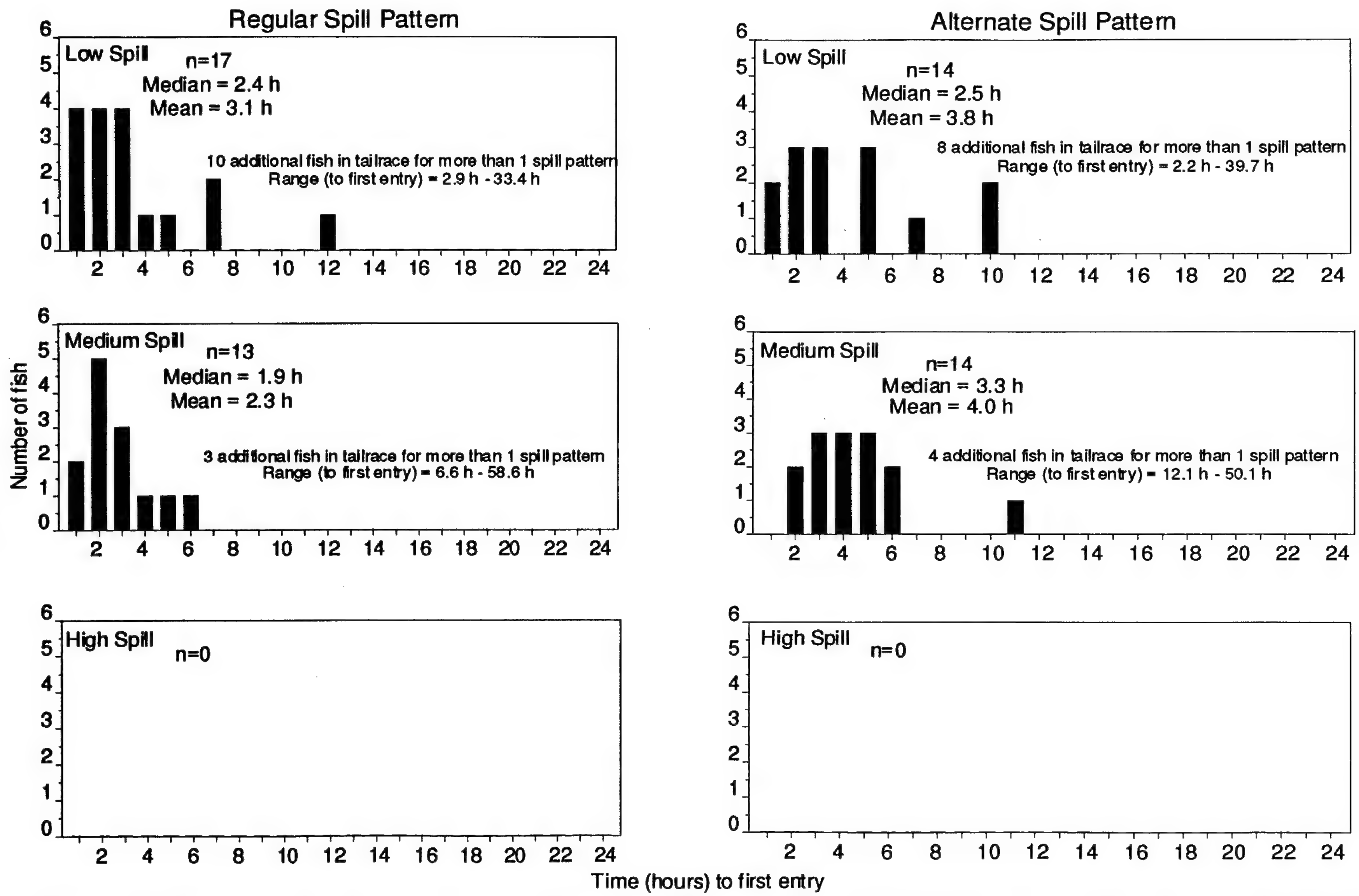


Figure 91. The number of chinook salmon and the elapsed time from their entry into the tailrace to first entrance into the fishway at Lower Granite Dam during regular and alternate spill patterns at low, medium and high spill levels in 1993.

spill pattern and took between 6.6 h and 2.4 days to enter, and an additional four fish that entered the fishway during the alternate spill pattern and took between 12.1 h and 2.1 days to do so. There were no fish recorded entering the fishway at high levels of spill during the regular or alternate spill pattern.

Chinook salmon that made their first entry into the fishway while exposed to only one spill pattern, used mostly the south and north shore entrances in addition to the north powerhouse entrances (Figure 92). During the regular spill pattern and at low levels of spill, 35% of the first entrances were at the north shore entrance and 35% at NPE-1 and -2 combined, and 18% at SSE-1 and -2. During the alternate spill pattern, 50% of the first entrances occurred at NPE-1 and -2, 21% at SSE-1, and 14% at the north shore entrance. During the regular spill pattern at medium levels of spill, 39% of the fish first entered the fishway via SSE-1 and -2 combined, and 31% in the north shore entrance. During the alternate spill pattern, 79% first entered at the north shore entrance and the remainder entered in either SSE-2, or OG-1 or -10.

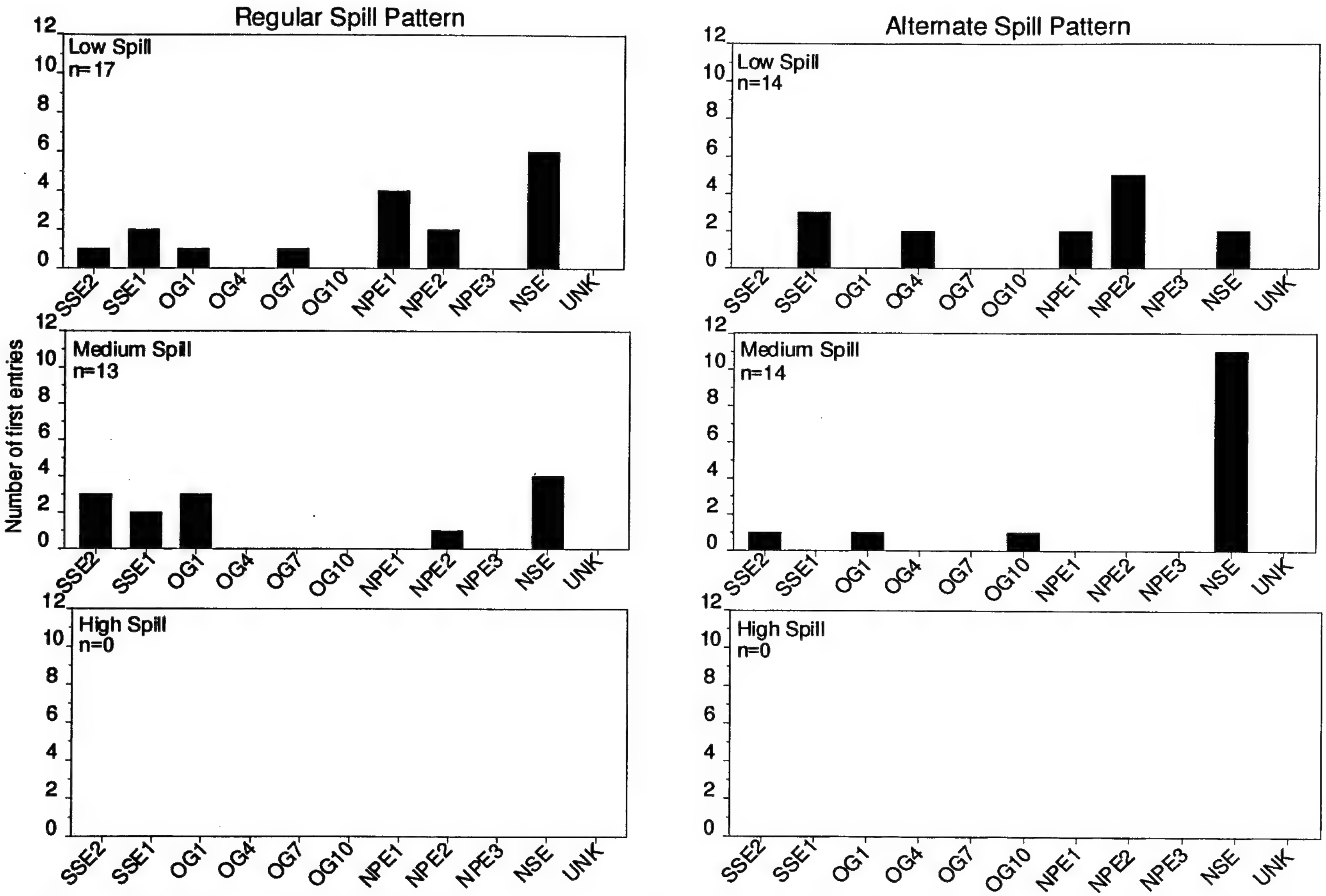


Figure 92. Entrances used by chinook salmon that made their first entry into the Lower Granite Dam fishway after having been exposed to only one spill pattern and level of spill in 1993.

Chinook Salmon - Fallback in 1993

As part of the analysis of fish behavior during spill conditions, we determined the number of chinook salmon that fell back past the lower Snake River dams during the various spill and no spill conditions. A fish was considered a fallback when recorded at a tailrace receiver after having been recorded on the upstream side of a dam. In two cases, fish were not recorded at the tailrace receiver site, but were recorded even further downstream, evidence that the fish had passed the dam, but the date and time of the fallback was unknown. There was no evidence that any of the fish that fell back did so via the ladders.

Nineteen of 339 chinook salmon (5.6%) that passed Ice Harbor Dam during the spring and early summer of 1993 fell back past one or more of the lower Snake River dams a total of 36 times and one fish fell back at McNary Dam (Table 4). Ten salmon fell back once, four fell back twice, two fell back three times, two fish four times, and one fish five times.

Seven fish fell back a total of 10 times at Ice Harbor Dam between 31 May and 17 August 1993 (Table 4). Half of the fallbacks (n=5) were during the period with no daytime spill (24 June - 17 August). Four of 10 occurred when hourly average spill volumes were between 25.3 and 39.4 kcfs (27 May - 18 June). We were unable to determine the date when the other fallback occurred.

Six fish fell back over Lower Monumental Dam and each fish fell back once (Table 4). Two of the six were during no spill periods (2 and 13 August) and the remaining fish (n=4) fell back when the volume of spill was 23.1, 30.7, 50.9 and 71.7 kcfs between 21 May and 13 June.

Nine fish fell back at Little Goose Dam a total of 12 times (Table 4). Four of the 12 fallbacks occurred during no spill periods between 10 June and 31 July. Seven of the 12 (58.3%) occurred from 15 May to 2 June when spill ranged from 31.5 to 94.2 kcfs. We were unable to determine the date when the other fallback occurred.

Eight fish fell back at Lower Granite Dam and each fish fell back once (Table 4). Half of the fallbacks (n=4) occurred during periods of no spill between 3 - 28 June. The remainder of the fallbacks (n=4) occurred at volumes of spill from 19.1 to 71.8 kcfs between 13 May - 8 June.

Of the nineteen chinook salmon that fell back over the dams, nine (47.4%) survived and moved upstream to spawning grounds or hatcheries where they were recaptured at weirs/traps (Table 4). Four of the 9 were recaptured in the Tucannon River, and one each at facilities in the South Fork of the Clearwater River, Lochsa River, Lookingglass Creek, Rapid River, and the South Fork of the Salmon River.

Nine of the nineteen salmon (47.4%) were last recorded in the lower Snake River after falling back over one or more dams, and two were last recorded downstream from the Snake River (Table 4). One fish was last recorded downstream from Ice Harbor Dam, another downstream from Lower Monumental Dam, three downstream from Little Goose Dam, and three downstream from Lower Granite Dam. One of the fish last recorded downstream from the Snake River, was found in the Columbia River 16 river km downstream from the mouth of the Snake River, and the other moved downstream over the two lowest dams in the Snake River and the four dams in the lower Columbia River and was found dead in the Sandy River.

Table 4. Site of fallback, date and time of fallback record, spill volume, and fate (last record) of chinook salmon that fell back over lower Snake River dams in 1993.

Fish no.	Fallback site	Date and time	Spill (kcfs)	Fate of fish
1.	Lower Granite	13 May; 22:05	41.5	downstream to Little Goose.
	Little Goose	15 May; 05:13	78.8	reascend Little Goose.
	Little Goose	17 May; 14:51	68.7	reascend Little Goose.
	Little Goose	22 May; 23:34	94.2	recaptured in Tucannon River on 16 August.
2.	Lower Granite	8 June; 05:31	19.1	last recorded at L. Goose.
3.	Little Goose	17 June; 02:44	0.0	last recorded at L. Goose.
4.	Lower Granite	3 June; 01:42	33.5	downstream to Little Goose.
	Little Goose	unknown		recaptured in Tucannon River on 14 September.
5.	L. Monumental	24 May; 18:10	23.1	downstream to Ice Harbor.
	Ice Harbor	unknown		found dead in Sandy River on 22 June.
6.	Ice Harbor	12 June; 22:49	39.4	reascend Ice Harbor; last recorded at Lower Granite.
7.	Ice Harbor	24 June; 07:27	0.0	last recorded in South Fork of Salmon River.
8.	Little Goose	19 May; 16:47	55.7	to Lower Monumental.
	L. Monumental	21 May; 09:34	71.7	to Ice Harbor.
	Ice Harbor	27 May; 17:26	25.8	reascend Ice Harbor and recaptured in Lochsa R. on 15 September.
9.	Ice Harbor	18 July; 10:45	0.0	reascend Ice Harbor.
	Little Goose	31 July; 04:58	0.0	to Lower Monumental.
	L. Monumental	13 August; 13:11	0.0	to Ice Harbor.
	Ice Harbor	15 August; 21:12	0.0	reascend Ice Harbor.
	Ice Harbor	17 August; 17:23	0.0	last recorded in Snake River downstream of Ice Harbor

Table 4. Continued.

Fish no.	Fallback site	Date and time	Spill (kcfs)	Fate of fish
10.	Lower Granite	16 May; 02:52	71.8	reascend Lower Granite and recaptured at Lookingglass Hatchery.
11.	Little Goose	30 May; 08:22	31.5	reascend Little Goose.
	Lower Granite	3 June; 20:31	0.0	to Little Goose.
	Little Goose	10 June; 06:15	0.0	recaptured in Tucannon River on 14 September.
12.	Ice Harbor	31 May; 22:49	26.0	to McNary Dam.
	McNary	4 June; 13:00		to Snake River.
	L. Monumental	13 June; 05:55	30.7	to Ice Harbor Dam.
	Ice Harbor	18 June; 01:53	25.3	to L. Monumental and recaptured in South Fork Clearwater River on 11 August.
13.	Lower Granite	12 June; 06:24	0.0	last recorded at L. Granite.
14.	Lower Granite	26 June; 18:26	0.0	to Little Goose Dam.
	Little Goose	1 July; 15:53	0.0	last recorded at L. Goose.
15.	Little Goose	27 May; 18:18	40.1	to Lower Granite and recaptured at Rapid River trap on 6 July.
16.	L. Monumental	2 August; 20:38	0.0	last recorded at Lower Monumental.
17.	Lower Granite	28 June; 04:24	0.0	last recorded at L. Granite.
18.	Ice Harbor	6 July; 16:26	0.0	last recorded in Columbia River in McNary pool.
19.	Little Goose	2 June; 12:13	75.9	to Lower Monumental.
	L. Monumental	3 June; 05:50	50.9	recaptured in Tucannon River on 29 June.

Chinook Salmon - 1993 North Powerhouse Entrance Test

A high exit rate of fish has been observed at the north powerhouse entrances of the fishways at Lower Granite and Little Goose dams (Turner et al. 1982; 1983). Fences were installed in the collection channels adjacent to the powerhouse at each dam to guide fish past the two entrances when they were migrating upstream in the collection channel. From the 1992 studies (Bjornn et al. 1994), we found that many steelhead moved downstream in the collection channel, and if they moved as far as the north end of the powerhouse and were on the tailrace side of the channel, the fence would guide them to the north powerhouse entrances where they might leave the fishway, just the opposite of the intended purpose of the fence. The fishway fence at Lower Granite Dam was removed in February 1993 and the fence at Little Goose Dam was left in place to provide a comparison of fishways with and without the fence.

In spring and early summer 1993, we monitored chinook salmon use of north powerhouse entrances 1 and 2 (NPE-1 and -2) to the fishway at Lower Granite and Little Goose dams to determine which of the two entrances were the most effective for fish passage and if the presence or absence of a fishway fence made a difference in the number of fish exiting the fishway at those two entrances. Chinook salmon with transmitters were monitored as they entered and exited the two entrances as described in previous sections where we used the digital spectrum processors and receivers. NPE-1 and -2 were the only entrances open during the test. The NPE-3 entrance, which faces into the spill basin, was kept closed because spill persisted until 20 June 1993.

At Little Goose Dam where the fishway fence was retained, fish exiting the fishway through NPE-1 and -2 openings exceeded entries by 75 and 60 salmon, respectively, (Figure 41, page 69). At Lower Granite Dam where the fishway fence had been removed, fish exiting the fishway exceeded those entering by 50 salmon at NPE-1, but at NPE-2, 75 more fish entered than exited (Figure 50, page 79).

We also analyzed the movements of 150 randomly selected fish passing Little Goose and Lower Granite dams (about one-half of all fish at each dam) to evaluate the role of the north powerhouse entrances. For salmon that entered the north powerhouse entrances, the direction traveled and entrance used prior to exiting either north powerouse entrance was assessed. Successful passage after entering the north powerhouse entrances was defined as a fish entering either NPE-1 or -2 and moving away from those entrances to be recorded on another antenna inside the collection channel. Unsuccessful passage at the north powerhouse entrances was a fish that entered and exited one of the north powerhouse entrances, but was not recorded on any other antenna inside the collection channel.

At Lower Granite Dam, 83% and 78%, respectively, of the fish that entered NPE-1 and -2 entered the fishway successfully and were recorded elsewhere in the fishway

(Table 5). Of those fish that entered, but then exited the fishway via NPE-1 or -2 before being recorded elsewhere in the fishway, the fish tended to exit through the opening they used to enter the fishway. At Little Goose Dam, a slightly lower percentage of the fish entered successfully (66% and 76% for fish using NPE-1 and -2, respectively) than at Lower Granite Dam. Salmon that exited the fishway at Little Goose Dam before moving into the collection channel enough to get recorded on other receivers most often used the opening they used to enter the fishway.

Table 5. Number of adult chinook salmon that entered north powerhouse entrances 1 (NPE-1) and 2, and moved successfully into the fishway versus those that entered, but then exited before moving into the fishway.

	Number of fish	Entered successfully	Entered then exited	Opening used to exit NPE-1	NPE-2
Lower Granite Dam					
NPE-1	80	66	14	9	5
NPE-2	125	97	28	11	17
Little Goose Dam					
NPE-1	35	23	12	9	3
NPE-2	42	32	10	2	8

About 90% of the fish exiting from north powerhouse entrances at Lower Granite and Little Goose dams in 1993 were moving south-to-north (downstream) in the collection channels prior to exiting the fishways (Table 6). Fish that had entered the fishway from all of the open entrances moved downstream in the collection channel before exiting via the north powerhouse entrances. The largest numbers of fish that left the fishways via the powerhouse entrances at both dams had entered the fishways at the north powerhouse entrances, at the south shore entrances, and at the north shore entrances. Fish that entered the fishway via the other entrances were not as numerous as fallouts at the powerhouse entrances because not many fish entered via the other entrances.

Many fish entered the north shore entrance, but were recorded as moving downstream prior to exiting the fishway at one of the north powerhouse entrances (Table 6). These fish had to swim upstream in the collection channel past the north powerhouse entrances far enough to be recorded on receivers upstream from the north powerhouse entrances, changed direction in the fishway, and then swam downstream to exit at the north powerhouse entrances. A smaller number of fish entered the north shore entrance and exited via the north powerhouse entrances without being recorded further upstream in the collection channel. At Lower Granite Dam, 7 of 19 salmon that entered the fishway via the north shore entrance and exited via the two north powerhouse entrances were swimming upstream prior to leaving the fishway. At Little

Goose Dam, 12 of 35 salmon entered the fishway via the north shore entrance and then exited without moving upstream past the north powerhouse entrances enough to be recorded on upstream receivers. The similar proportions (about one-third) of north shore entry fish that left the fishways at the north powerhouse entrances while moving upstream in the fishways at the two dams is evidence that the fishway fence at Little Goose Dam did not prevent more exits of those fish than at Lower Granite Dam where no fence was in place during 1993.

Salmon that entered the fishways at the two dams at the south shore and orifice gate 1 entrances and then exited via the north powerhouse entrances were all moving downstream (with one exception) prior to exiting the fishways (Table 6). Of the fish exiting the fishways at the two dams via the north powerhouse entrances, 28% of those at Lower Granite Dam, and 33% of those at Little Goose Dam, had entered via the south shore and orifice gate 1 entrances. Despite removal of the fence at Lower Granite Dam prior to the migration in 1993, a substantial number of salmon exited the fishway via the north powerhouse entrances.

Table 6. Number of adult chinook salmon that exited the fishways at Lower Granite and Little Goose dams via north powerhouse openings 1 (NPE-1) and 2, and the direction of movement in the fishway prior to leaving the fishway, by entrance used to enter the fishways in 1993.

	Lower Granite Dam		Little Goose Dam	
	Upstream	Downstream	Upstream	Downstream
Exits at NPE-1				
Entrances for entry				
South shore entrance-1	1	7	-	-
South shore entrance-2	0	5	0	15
Orifice gate-1	0	7	0	4
Orifice gate-4	0	2	0	0
Orifice gate-6	0	3	0	5
Orifice gate-10	0	1	0	2
North powerhouse-1	0	14	0	4
North powerhouse-2	0	24	0	7
North shore	3	6	3	12
Totals	4	69	3	49
Exits at NPE-2				
Entrances for entry				
South shore entrance-1	0	3	-	-
South shore entrance-2	0	3	0	14
Orifice gate-1	0	6	0	5
Orifice gate-4	0	1	0	1
Orifice gate-6	0	3	0	6
Orifice gate-10	0	0	0	3
North powerhouse-1	0	8	0	9
North powerhouse-2	0	10	0	4
North shore	4	6	9	11
Totals	4	40	9	53

Steelhead - 1993 Migration Rates, Passage Success, and Distribution

Methods - Steelhead Tagged in 1993

Migration rates and passage at the dams and into the tributaries of the Snake River were assessed for steelhead tagged in 1993 in a manner similar to that described for chinook salmon. Receivers set up to monitor chinook salmon movements at the dams and mouths of the major tributaries were also used to monitor steelhead movements.

Capture and outfitting steelhead with transmitters at John Day Dam began in early July of 1993 and continued into the first week of August when temperatures of the Columbia River began to exceed 20°C. During July and early August, 251 steelhead were captured, outfitted with transmitters and visual-implant (VI) tags, and released in the south fish ladder at John Day Dam (Figure 93). Trapping was resumed when temperatures in the river had cooled, and 633 additional steelhead were captured and released with transmitters and VI tags from early September through the first week of November. Movements of fish released in July and August were monitored to provide information on the passage at dams and distribution of steelhead from the early segment of the run into the Snake River, and steelhead released with transmitters in the fall provided similar information on the latter segment of the run.

A major difference between the steelhead and chinook salmon portions of the telemetry work, was the presence of an active fishery in most of the Columbia and Snake River basins where steelhead migrated. Anglers captured many of the steelhead with transmitters and turned in many of the transmitters or tags to provide information and get the $5 reward.

Results - Steelhead Tagged in 1993

Passage success

Steelhead that were monitored as they migrated through the lower Snake River were divided into two groups based on time of release. Seventy-four percent of the steelhead released in July and August were classified as hatchery in origin (had an adipose fin clip), versus 81% of those released in the fall (Table 7).

Of the 251 steelhead released with transmitters in July and August of 1993, 17 entered the John Day River, 122 passed McNary Dam, 1 entered the Yakima River, 83 were recorded as entering the tailrace at Ice Harbor Dam, 67 at Lower Monumental Dam, 44 at Little Goose Dam, and 31 at Lower Granite Dam (Figure 94). Sixty-four of the 251 steelhead released in the summer were recaptured at the Lower Granite trap, 8 were recorded going into the Clearwater River, and 27 were recorded migrating up the Snake River near Asotin (Table 7). Thirty-three percent of the fish released in July were

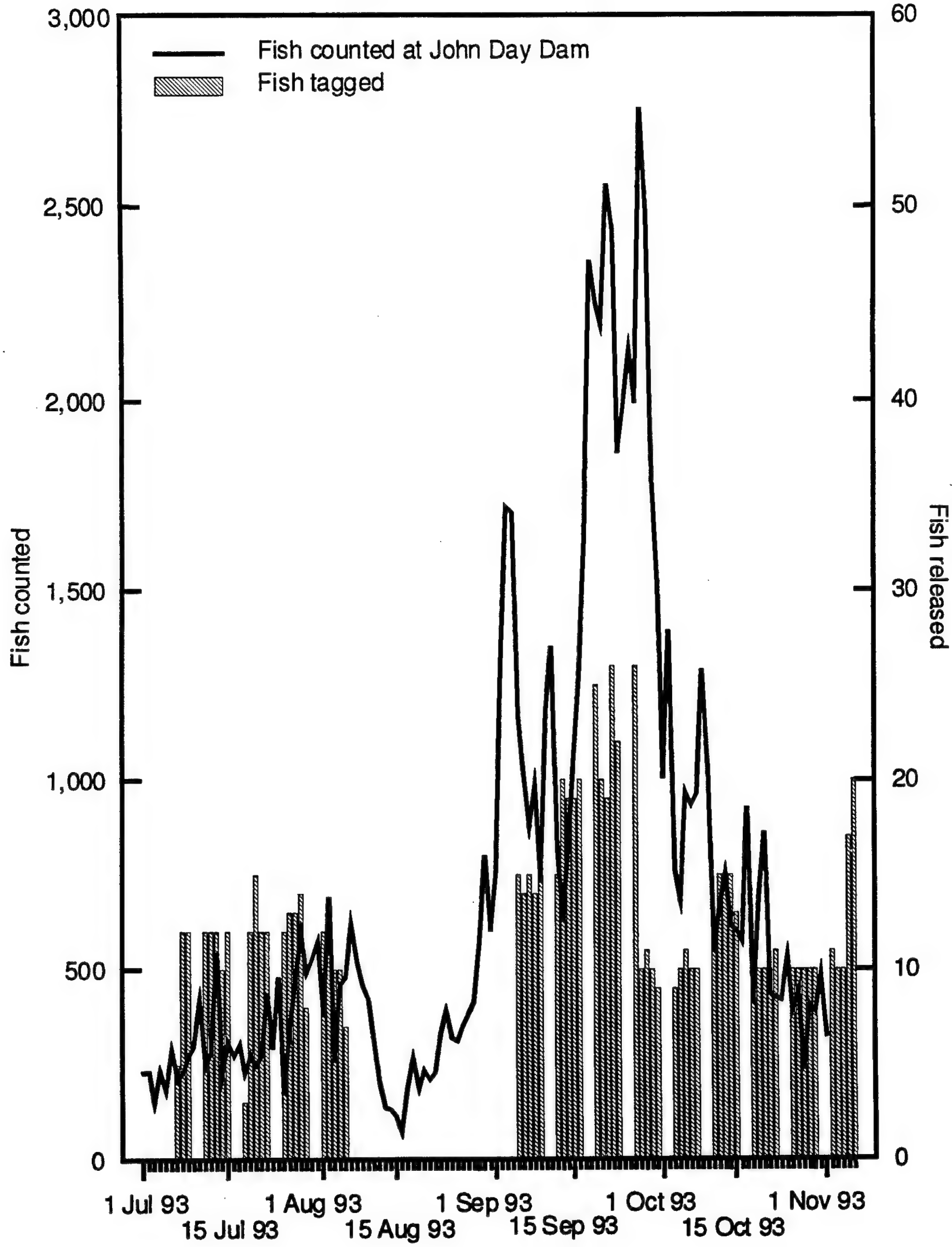


Figure 93. Number of steelhead counted daily and the number of steelhead released with radio transmitters at John Day Dam in the summer and fall of 1993.

Table 7. Number of steelhead released at John Day Dam in July and August and in the fall of 1993, and then recorded or recaptured at McNary Dam and sites in the lower Snake River.

	Released in the summer			Released in the fall		
Location/Activity	Total	Wild	Hatchery	Total	Wild	Hatchery
Fish released	251	66	185	633	118	515
McNary Dam	122	28	94	325	53	272
Ice Harbor Dam receivers						
Tailrace	83	19	64	249	37	212
Top of ladder	76	18	58	259	38	221
Lower Monumental Dam receivers						
Tailrace	67	16	51	154	28	126
Top of ladder	71	17	54	235	36	199
Little Goose Dam receivers						
Tailrace	44	12	32	180	30	150
Top of ladder	46	14	32	244	37	207
Lower Granite Dam receivers						
Tailrace	31	11	20	141	21	120
Top of ladder	40	13	27	225	34	191
Lower Granite Dam adult trap	64	20	44	260	43	217
Upstream from Lower Granite Dam						
Clearwater R.	8	3	5	87	19	68
Snake R.	27	9	18	104	15	89

recorded as having entered the Ice Harbor Dam tailrace, 30% were recorded exiting the top of the ladder and 25% were recaptured in the trap at Lower Granite Dam.

Of the 633 steelhead released at John Day Dam with transmitters in the fall of 1993, 90 entered the John Day River, 325 passed McNary Dam, 249 were recorded as entering the tailrace at Ice Harbor Dam, 154 at Lower Monumental Dam, 180 at Little Goose Dam, and 141 at Lower Granite Dam (Figure 94). Two-hundred sixty of the fish released in the fall were recaptured at the Lower Granite adult trap, 87 were recorded going into the Clearwater River, and 104 were recorded migrating up the Snake River near Asotin (Table 7). Thirty-nine percent of the 633 fish released in the fall were

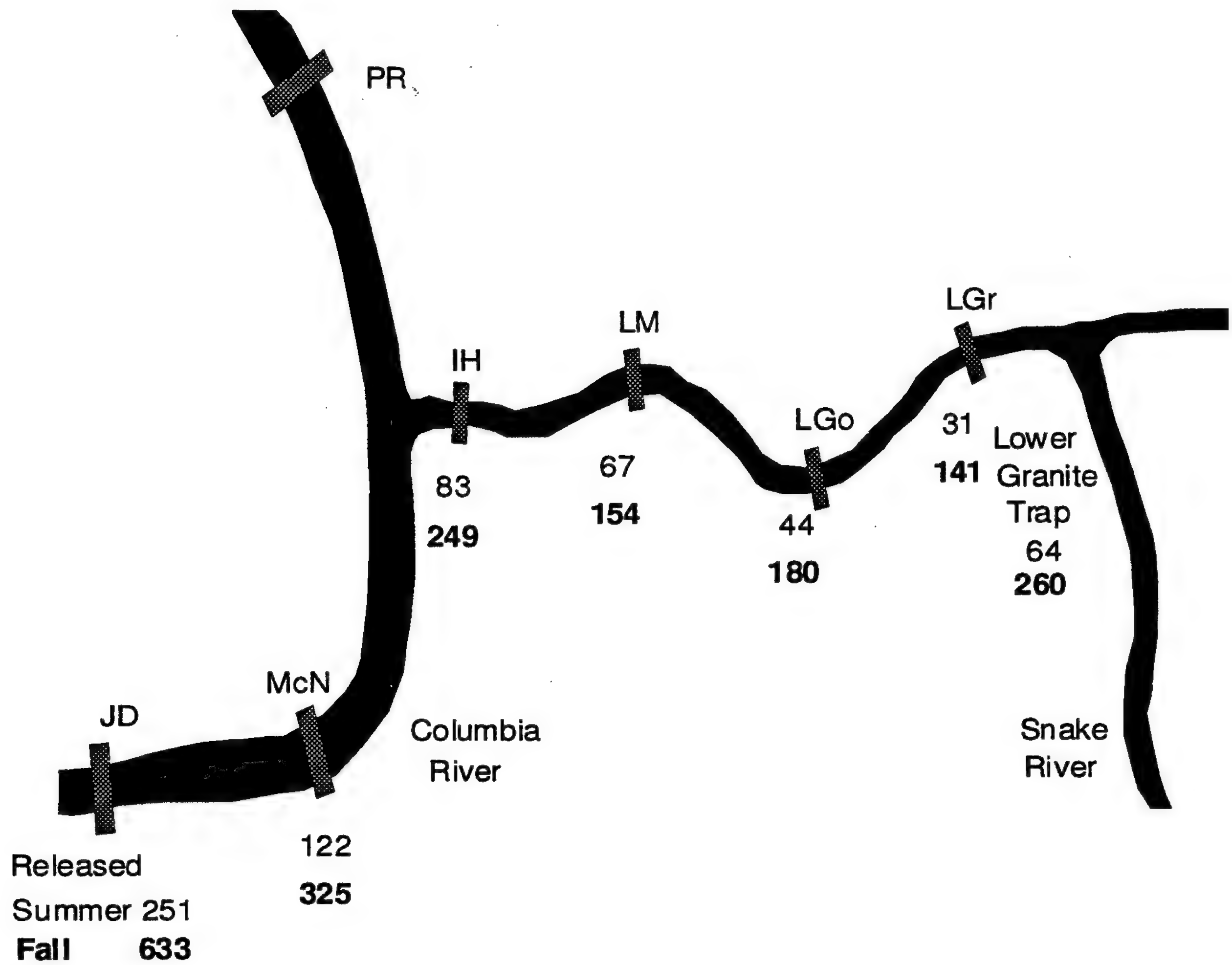


Figure 94. Map of the lower Columbia and Snake rivers with the number of steelhead released at John Day Dam (JD) in the summer and the fall (bold type)of 1993, and the number of fish recorded on receivers in the tailrace of each of the dams and recaptured at the Lower Granite trap during the fall of 1993 through spring of 1994.

recorded in the Ice Harbor tailrace, 41% were recorded exiting the ladder and 41% were recaptured in the trap at Lower Granite Dam.

The percentages of steelhead released that were recaptured at the Lower Granite trap were 25% for those released in July and August and 41% for those released in the fall of 1993. Removal of fish by the fishery downstream from Lower Granite Dam is a partial explanation for the reduced proportions passing upstream; about 3.3% and 12.7% of the steelhead with transmitters were reported caught by anglers from the lower Snake River downstream from Lewiston and from the Columbia River and its tributaries, respectively. In addition, some steelhead spend the winter in the downstream reservoirs and the losses before passage may be higher than for chinook salmon because salmon spend relatively little time in the lower Snake River. Steelhead migrating upstream in July and August encounter river temperatures that exceed 20° C in the Snake River.

Smaller proportions of the steelhead classified as wild versus hatchery and released in the fall of 1993 migrated upstream past the dams, but a smaller proportion of the hatchery fish than wild fish released in the summer were recorded or recaptured upstream from Ice Harbor Dam (Table 8). Only eight of the steelhead released in July entered the Clearwater River versus 27 that were recorded in the Snake River near Asotin (Table 7). For the steelhead released in the fall, both hatchery and wild fish entered the Clearwater and Snake rivers upstream from Lewiston, with the numbers reflecting, perhaps, the proportions of hatchery and naturally produced fish in the various drainages.

Table 8. Number of wild and hatchery steelhead released at John Day Dam in the summer and fall of 1993, and the percent recorded or recaptured at various upstream locations.

	Summer release		Fall release	
	Wild	Hatchery	Wild	Hatchery
Fish released	66	185	118	515
Percent recorded at:				
Ice Harbor tailrace	29	35	31	41
Lower Granite tailrace	17	11	18	23
Lower Granite trap	30	24	36	42
Upstream from Lower Granite Dam	32	24	38	45

Migration rates

Median passage time from the release site in the south shore fish ladder to the top of the ladder at John Day Dam was 0.9 d for steelhead released in the summer and 0.2 d for those released in the fall of 1993 (Table 9). Fish migrated rapidly through the John Day and McNary pools, with median travel times from the top of John Day Dam to the top of McNary Dam of about 4 d. Median passage times from the top of McNary Dam to the tailrace at Ice Harbor Dam were 2.5 and 3.0 d, respectively, for fish released in the summer and in the fall (Table 9). The above rates are for fish that passed Lower Granite Dam before 31 December 1993, and represent fish intent on migrating past the dams in the summer and fall of 1993. Fish that spent the winter in the Columbia or Snake rivers downstream from Lower Granite Dam migrated at slower rates (Table 9).

The median time for steelhead released in the fall to pass the four lower Snake River dams in 1993 ranged from a high of 1.0 d at Lower Granite Dam to a low of 0.3 d at Liittle Goose Dam (Table 9). Median passage times for steelhead released in July and August of 1993 were more variable (0.6 to 1.5 d) than those of fish released in the fall. The

Table 9. Mean and median number of days for steelhead to migrate from the release site in the lower part of the John Day Dam fish ladder to the top of the ladder, and from the top of the John Day and McNary dam ladders to upstream dams, and the days to pass each of the four dams in the lower Snake River for fish passing Lower Granite Dam before 31 December 1993.

	Number of fish	Mean number of days	Range of days	Median number of days
Release to the top of John Day Dam				
Fish released in summer	48	8.9	0.1-83.9	0.9
Fish released in fall	126	2.5	0.04-34.4	0.2
Top of John Day to top of McNary dams				
Fish released in summer	43	5.7	2.0-25.1	4.0
Fish released in fall	110	6.0	2.2-22.1	4.8
Top of McNary to tailrace at Ice Harbor dams				
Fish released in summer	41	5.3	1.0-57.8	2.5
Fish released in fall	165	5.4	1.1-44.5	3.0
Top of John Day to tailrace at Ice Harbor dams				
Fish released in summer	39	11.3	3.8-60.9	6.9
Fish released in fall	107	12.3	3.6-50.5	9.2
Past a Snake River dam				
Ice Harbor				
Fish released in summer	41	1.8	0.2-18.1	1.0
Fish released in fall	162	1.1	0.1-11.8	0.7
Lower Monumental				
Fish released in summer	37	1.9	0.2- 34.4	0.7
Fish released in fall	88	0.7	0.1-5.7	0.4
Little Goose				
Fish released in summer	31	1.5	0.1 - 19.4	0.6
Fish released in fall	124	0.7	0.1 - 18.8	0.3
Lower Granite				
Fish released in summer	27	2.5	0.3 - 11.1	1.5
Fish released in fall	97	1.8	0.1 - 19.9	1.0

above listed rates were for fish that crossed over Lower Granite Dam before 31 December 1993. For fish that did not pass Lower Granite Dam until after 31 December (mostly in March and April of 1994), the time to pass a dam was more variable and extended (up to a mean of 26.0 d and median of 1.5 d, Table 10) than for fall migrating fish.

The distribution of passage times was similar at the four lower Snake River dams for steelhead released in the fall and migrating past Lower Granite Dam in the fall (Figure 95), with a high percentage of the fish passing within 10 d, and most passing within 48 hours. Fish may have taken slightly longer to pass Lower Granite Dam because of the trap operated in the south ladder of the dam, but 97.9% of the fish took less than 10 days to pass the dam.

Median passage time for steelhead that migrated through the lower Snake River in the fall of 1993 was higher at Ice Harbor and Lower Granite dams, than at Lower Monumental and Little Goose dams. Time required for a fish to pass a dam was measured as the lapsed time from the last record of a fish at the tailrace receivers to the last record from the same fish on a receiver/antenna at the top of the ladders.

The distribution of passage times at three Snake River dams for steelhead released in July and August and migrating past Lower Granite Dam before 31 December 1993 was similar with most fish crossing the dams within 48 hours (Figure 96). Fewer than 4% of the fish took more than 10 d to cross each of the three lower Snake River dams. Passage at Lower Granite Dam had a wider spread of the diistribution than the other dams, but 96.3% of the steelhead took less than 10 days to pass the dam.

In the fall of 1993, the fish trap at Ice Harbor Dam was operated on a different two-week schedule than in the previous two years to evaluate the effect of trapping of adults on passage rates. During the first 5 d of each two-week period, trapping was conducted to collect steelhead for the zero-flow study and chinook salmon brood stock for Lyons Ferry Hatchery. Trapping continued during the next 5 d to collect salmon brood stock, and then no trapping was conducted during the last 4 d of the period. During the 10 d when trapping was conducted in each two-week period, the trap was removed from the water as soon as trapping was completed and not returned to the water until the next morning of trapping. The 10 d of trapping and 4 d without trapping was adopted as the schedule in 1993 to accommodate the need to trap steelhead for the zero-flow study and broodstock for the hatchery, and to allow the evaluation of passage rates with and without trapping in the ladder. Because all steelhead released with transmitters were trapped and released at John Day Dam in 1993, passage at Ice Harbor Dam was evaluated with fish that had not passed that dam previously, as was not the case in 1991 and 1992.

Table 10. Mean and median number of days for steelhead to migrate from the release site in the lower part of the John Day Dam fish ladder to the top of the ladder, and from the top of the ladder to upstream dams, and the days to pass each of the four dams in the lower Snake River for fish passing Lower Granite Dam after 31 December 1993.

	Number of fish	Mean number of days	Range of days	Median number of days
Release to the top of John Day Dam				
Fish released in summer	2	115.9	0.1-231.8	115.9
Fish released in fall	47	14.2	0.1-163.9	0.3
Top of John Day to top of McNary dams				
Fish released in summer	1	2.8		
Fish released in fall	35	57.2	2.4-176.1	9.0
Top of McNary to tailrace at Ice Harbor dams				
Fish released in summer	0			
Fish released in fall	34	27.4	0.9-185.9	6.1
Top of John Day to tailrace at Ice Harbor dams				
Fish released in summer	0			
Fish released in fall	29	87.7	3.3-190.1	75.3
Past a Snake River dam				
Ice Harbor				
Fish released in summer	0			
Fish released in fall	34	26.0	0.1 - 178.3	0.5
Lower Monumental				
Fish released in summer	1	0.4		
Fish released in fall	34	6.1	0.1 - 74.6	0.6
Little Goose				
Fish released in summer	1	0.4		
Fish released in fall	36	15.9	0.01 - 115.0	0.6
Lower Granite				
Fish released in summer	0			
Fish released in fall	28	4.2	0.2 - 49.4	1.5

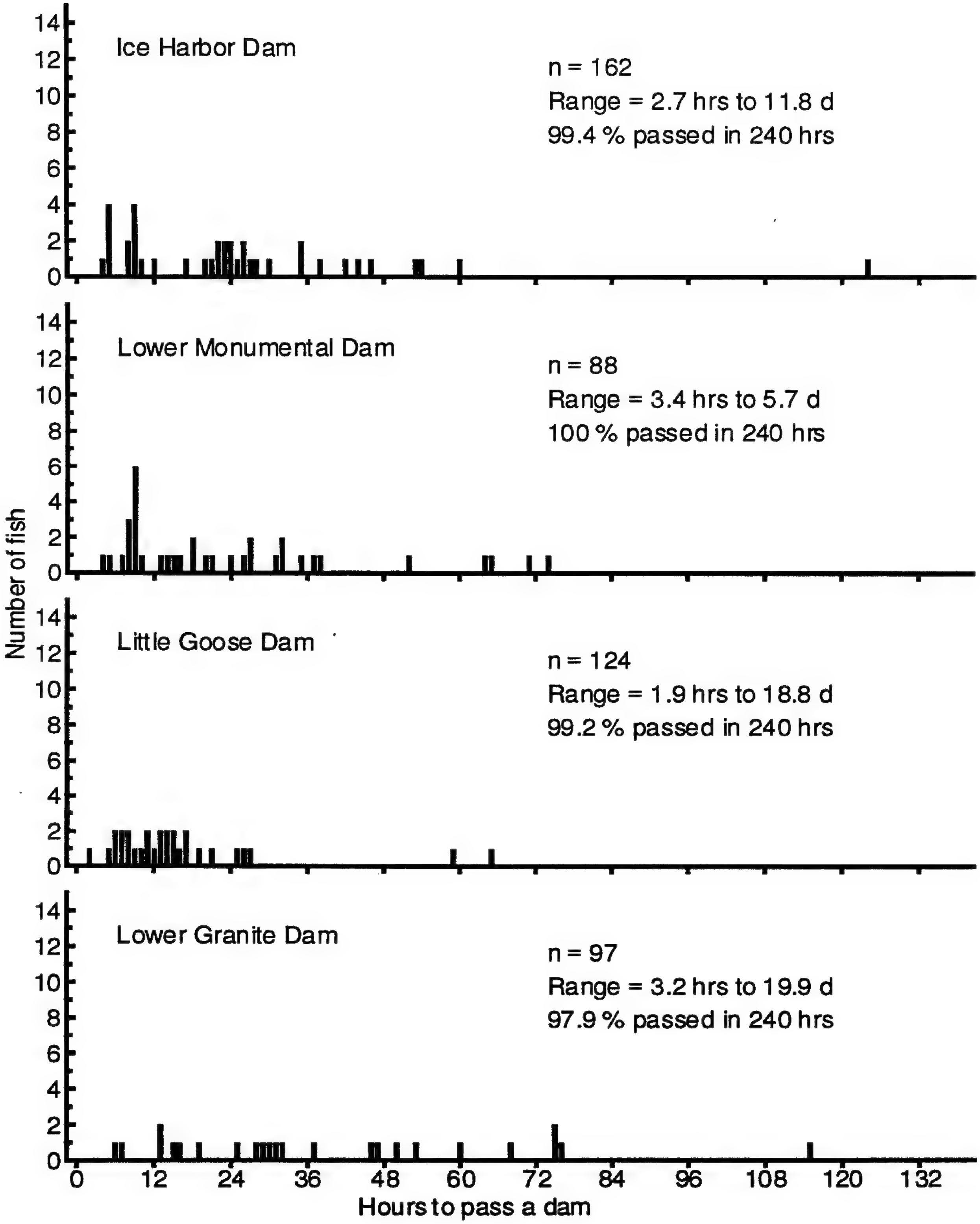


Figure 95. Frequency distribution of the time for steelhead to pass dams in the lower Snake River in 1993. Steelhead released John Day Dam in the fall that crossed over Lower Granite Dam before 31 December 1993.

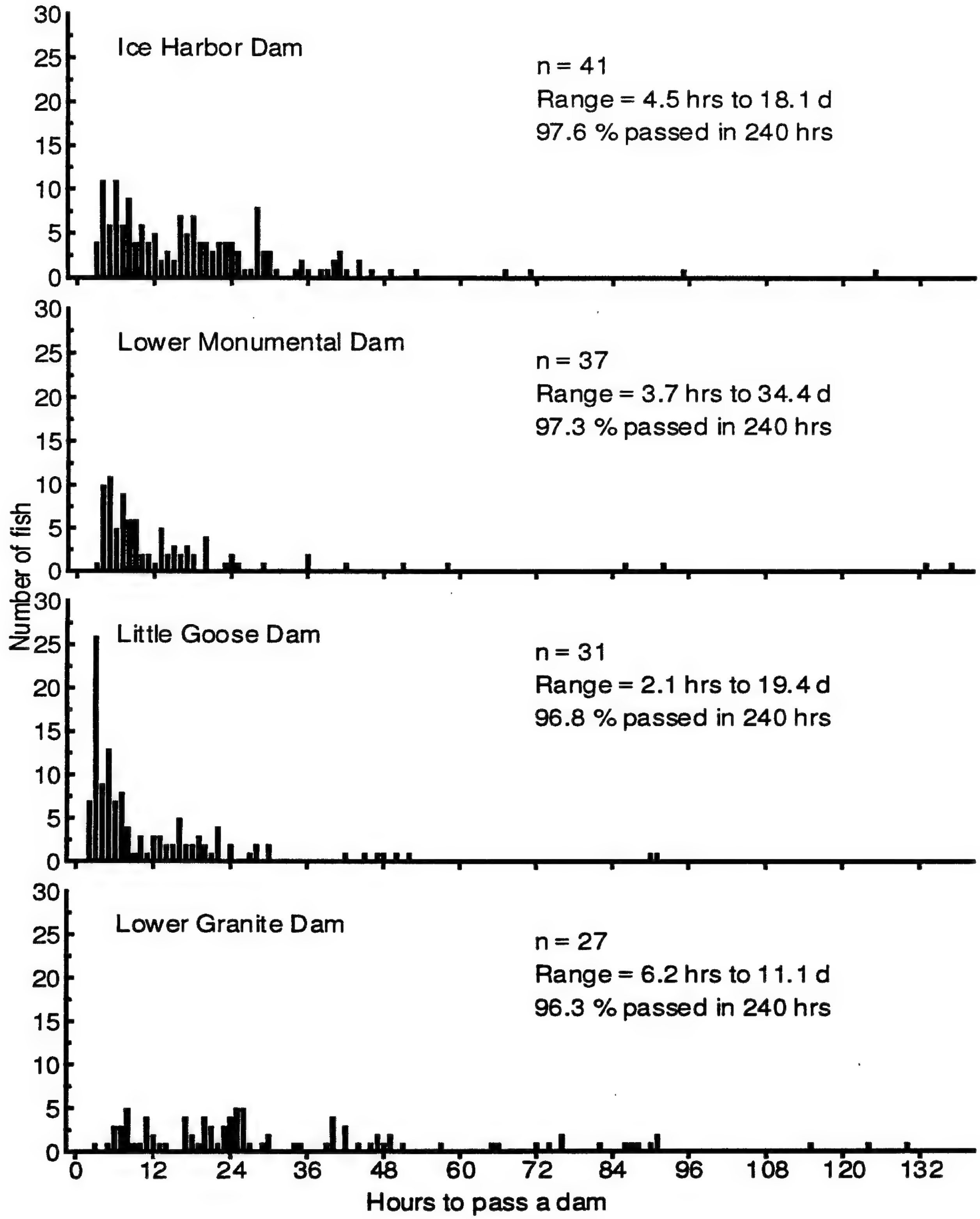


Figure 96. Frequency distribution of the time for steelhead to pass dams in the lower Snake River in 1993. Steelhead released at John Day Dam in July and August that crossed over Lower Granite Dam before 31 December 1993.

Passage up the south ladder at Ice Harbor Dam was calculated by subtracting the time of the last record for a fish at the bottom of the ladder from the time of the last record at the top of the ladder. Steelhead that arrived at the bottom of the ladder on a day when trapping occurred took an average of 0.6 d (median 0.4 d) to pass from the bottom to the top of the ladder, compared to 0.2 d on average (median 0.1 d) for fish that arrived on days when there was no trapping. Passage times were slower and more variable for steelhead that passed the dam when trapping occurred versus when there was no trapping (Figure 97).

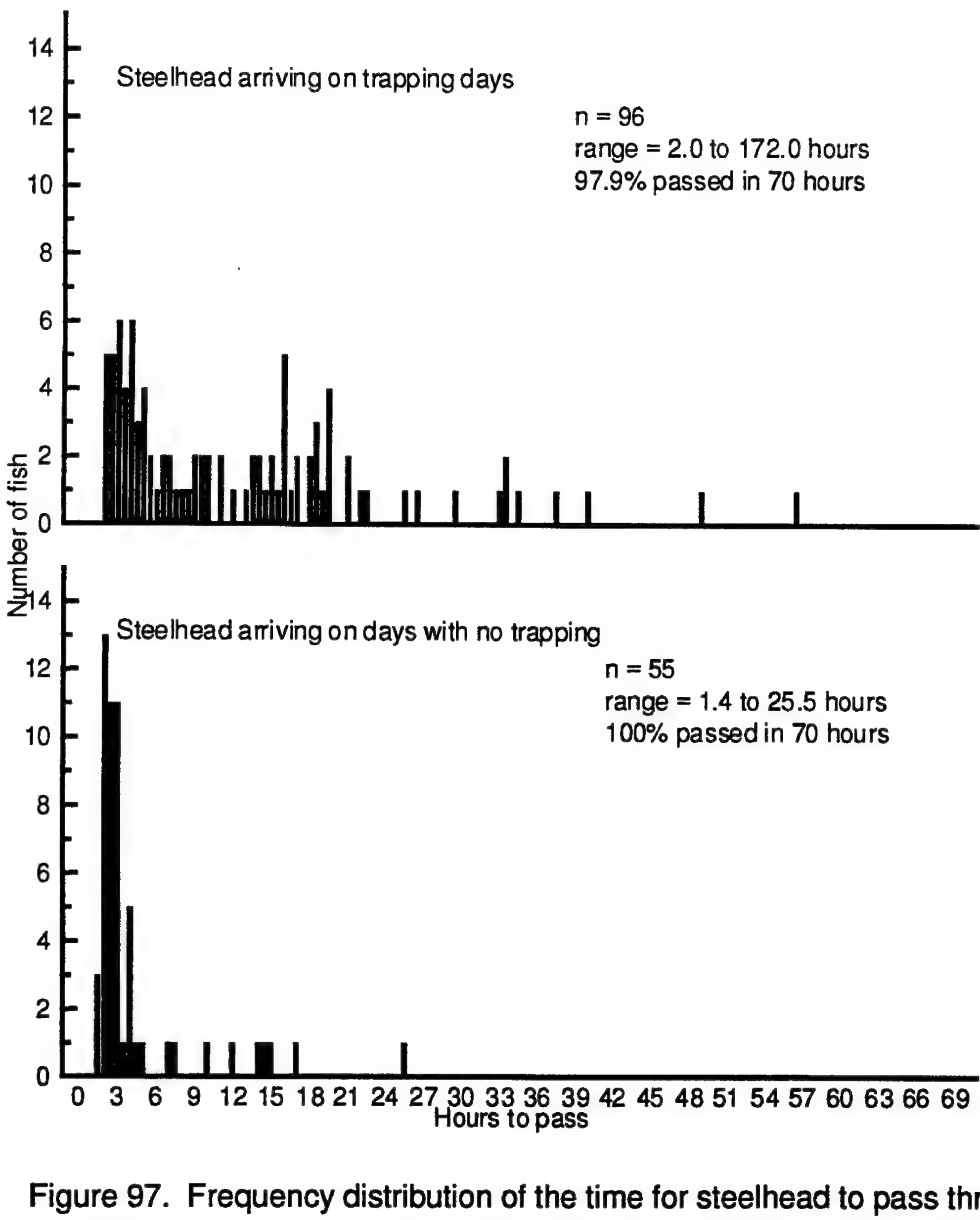


Figure 97. Frequency distribution of the time for steelhead to pass through the south shore ladder at Ice Harbor Dam in 1993, that were released with transmitters at John Day Dam in 1993, crossed over Lower Granite Dam before 31 December 1993, and passed Ice Harbor Dam during the trapping season - 1 September to 10 November.

Migration rates through the reservoirs of steelhead that migrated over Lower Granite Dam before 31 December 1993, ranged up to 26.9 km/d based on the mean migration rate and 35.6 km/d for the median migration rate (Table 11). Steelhead that did not cross Lower Granite Dam until after 31 December moved rapidly through the upper reservoirs once they decided to resume their upstream migration, but the rates of movement were more variable than for the fish that migrated in the fall (Table 12, Figures 98 and 99), but the sample sizes were small.

Migration rates of steelhead in the free-flowing sections of the Snake, Clearwater, and Salmon rivers were slower than those in the reservoirs (Table 11). In the free-flowing rivers, steelhead migrated at median rates of about 10 or fewer km/d, versus rates in the reservoirs of 20-30 km/d. The slower migration rates in the rivers is mostly due to the fact that steelhead cease migrating in the late fall and spend the winter in the rivers. Many of the fish migrated out of Lower Granite Reservoir and into the Snake, lower Clearwater, and lower Salmon rivers where they ceased migrating in November or December and did not resume upstream movements until the next spring.

Most steelhead migrated through the individual lower Snake River reservoirs in less than 10 d, especially those steelhead that migrated past Lower Granite Dam before 31 December 1993. A few fish stayed in a single pool several months.

Recaptures of steelhead tagged in 1993

Of the 2,878 steelhead outfitted with transmitters or tagged with spaghetti-loop tags in 1993, reports were returned to us for 596 fish. Of the 596 fish, 328 had been taken in fisheries, 193 recaptured at hatcheries, 17 were captured and released at weirs, 10 were collected during electro-shocking surveys, 4 were found dead in the rivers, 39 transmitters were found on the banks or bottoms of streams without a fish carcass, and 5 recaptures were from unknown sources (Table 13) In addition, 1,799 of the tagged fish (62.5%) were recaptured in the Lower Granite trap from July 1993 through 11 April 1994.

Of the 328 steelhead with transmitters or spaghetti-loop tags that were reported caught in fisheries during the fall of 1993 and spring of 1994, 46 were fish that had moved downstream from their point of release before they were caught (Table 13). A total of 55 steelhead (9.2% of those recaptured, excluding recaptures at the Lower Granite trap) were recorded as having moved downstream from their site of release, with 2 fish trapped at weirs, 1 fish found dead, 6 transmitters were found without fish, and 46 steelhead were caught in fisheries (Figure 100).

The largest number of recoveries (123; 20.6% of the recaptured fish, Table 13) for a reach of river, was from the lower Snake River (mouth to Lewiston) where 65 tagged steelhead were caught by anglers, 40 entered Lyons Ferry Hatchery, 2 were caught from

Table 11. Migration rates of steelhead released in 1993 with transmitters at John Day Dam as they migrated through reservoirs and in free flowing sections of rivers as measured by fish recorded at receivers at the dams and at fixed location sites in the rivers for fish passing Lower Granite Dam before 31 December 1993. Movements are from the top of a dam to the tailrace of the next upstream dam unless otherwise noted.

Section of River	Number of fish	Mean travel rates Days	Mean travel rates Km/day	Median travel rates Days	Median travel rates Km/day
Through reservoirs					
Top of John Day to top of McNary dams					
Fish released in summer	43	5.7	21.6	4.2	29.3
Fish released in fall	111	6.1	20.1	4.9	25.1
McNary to Ice Harbor dams					
Fish released in summer	41	5.3	12.7	2.5	27.0
Fish released in fall	165	5.4	12.5	3.0	22.5
Ice Harbor to Lower Monumental dams					
Fish released in summer	37	2.0	25.0	1.6	31.2
Fish released in fall	97	1.9	26.3	1.4	35.6
Lower Monumental to Little Goose dams					
Fish released in summer	33	4.2	10.9	1.7	26.9
Fish released in fall	109	1.7	26.9	1.5	30.5
Little Goose to Lower Granite dams					
Fish released in summer	29	2.7	21.9	2.0	29.6
Fish released in fall	98	2.6	22.7	2.1	28.1
Lower Granite to Clearwater River site					
Fish released in summer	7	22.6	2.6	16.4	3.6
Fish released in fall	52	43.0	1.4	12.2	4.8
Lower Granite Dam to Snake River site					
Fish released in summer	25	15.6	4.1	2.8	22.8
Fish released in fall	93	6.8	9.4	2.6	24.6
Release to Clearwater River site					
Fish released in summer	8	47.5	8.6	33.6	12.1
Fish released in fall	53	68.3	6.0	43.0	9.5

Table 11. continued.

Section of River	Number of fish	Mean travel rates Days	Mean travel rates Km/day	Median travel rates Days	Median travel rates Km/day
Release to Snake River site					
Fish released in summer	26	74.0	5.6	71.8	5.7
Fish released in fall	94	28.8	14.3	22.9	18.0
Through Rivers					
Snake River to Grande Ronde River sites					
Fish released in summer	5	19.2	1.9	10.7	3.4
Fish released in fall	12	99.7	0.4	64.0	0.6
Snake River to Lower Salmon River sites					
Fish released in summer	9	30.5	6.7	11.3	18.1
Fish released in fall	40	123.8	1.7	135.5	1.5
Lower Salmon to South Fork Salmon sites					
Fish released in summer	0				
Fish released in fall	0				
Lower Salmon to Middle Fork Salmon sites					
Fish released in summer	4	124.7	1.4	157.4	1.1
Fish released in fall	21	59.4	3.0	16.0	11.3
Lower Salmon to Upper Salmon sites					
Fish released in summer	3	172.7	1.4	172.9	1.4
Fish released in fall	17	67.4	3.4	23.2	10.4

Table 12. Migration rates of steelhead with transmitters released in the fall of 1993 at John Day Dam as they migrated through reservoirs and in free flowing sections of rivers in 1993-1994 as measured by fish recorded at receivers at the dams and at sites along the rivers for fish passing Lower Granite Dam after 31 December 1993. Movements are from the top of a dam to the tailrace of the next upstream dam unless otherwise noted.

Section of River	Number of fish	Mean travel rates Days	Mean travel rates Km/day	Median travel rates Days	Median travel rates Km/day
Through reservoirs					
Top of John Day to top of McNary dams					
Fish released in summer	1	2.8	68.0		
Fish released in fall	36	55.8	3.4	8.4	22.7
McNary to Ice Harbor dams					
Fish released in summer	0				
Fish released in fall	35	26.4	2.6	5.1	13.2
Ice Harbor to Lower Monumental dams					
Fish released in summer	1	1.1	45.4		
Fish released in fall	33	15.7	3.2	2.1	23.8
Lower Monumental to Little Goose dams					
Fish released in summer	1	1.1	41.6		
Fish released in fall	30	5.4	8.5	1.2	38.2
Little Goose to Lower Granite dams					
Fish released in summer	0				
Fish released in fall	33	11.4	5.2	1.3	45.5
Lower Granite Dam to Clearwater River site					
Fish released in summer	0				
Fish released in fall	22	5.8	10.1	1.6	36.6
Lower Granite Dam to Snake River site					
Fish released in summer	1	1.4	45.6		
Fish released in fall	9	3.5	18.3	2.2	29.0
Release to Clearwater River site					
Fish released in summer	0				
Fish released in fall	34	171.8	2.4	170.3	2.4

Table 12. continued.

Section of River	Number of fish	Mean travel rates Days	Mean travel rates Km/day	Median travel rates Days	Median travel rates Km/day
Release to Snake River site					
Fish released in summer	1	242.7	1.7		
Fish released in fall	10	171.7	2.4	168.8	2.4
Through Rivers					
Snake River to Grande Ronde River sites					
Fish released in summer	1	0.8	45.0		
Fish released in fall	3	1.2	30.0	1.2	30.0
Snake River to Lower Salmon River sites					
Fish released in summer	0				
Fish released in fall	1	8.2	24.9		
Lower Salmon to South Fork Salmon sites					
Fish released in summer	0				
Fish released in fall	0				
Lower Salmon to Middle Fork Salmon sites					
Fish released in summer	0				
Fish released in fall	1	6.5	27.8		
Lower Salmon to Upper Salmon sites					
Fish released in summer	0				
Fish released in fall	1	9.5	25.4		

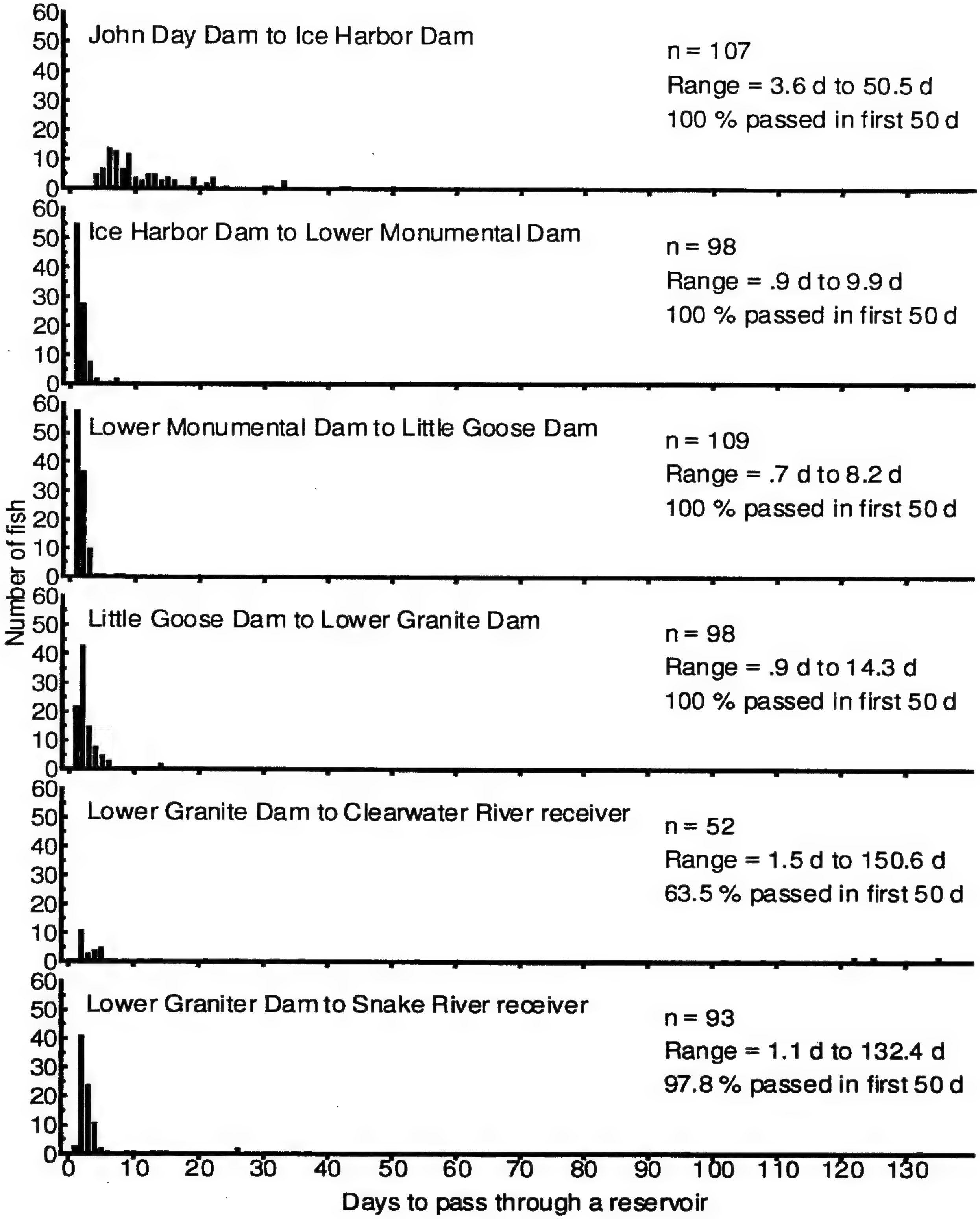


Figure 98. Frequency distribution of the time steelhead with transmitters took to pass through lower Snake River reservoirs in 1993. Steelhead released at John Day Dam in the fall that crossed over Lower Granite Dam before 31 December 1993.

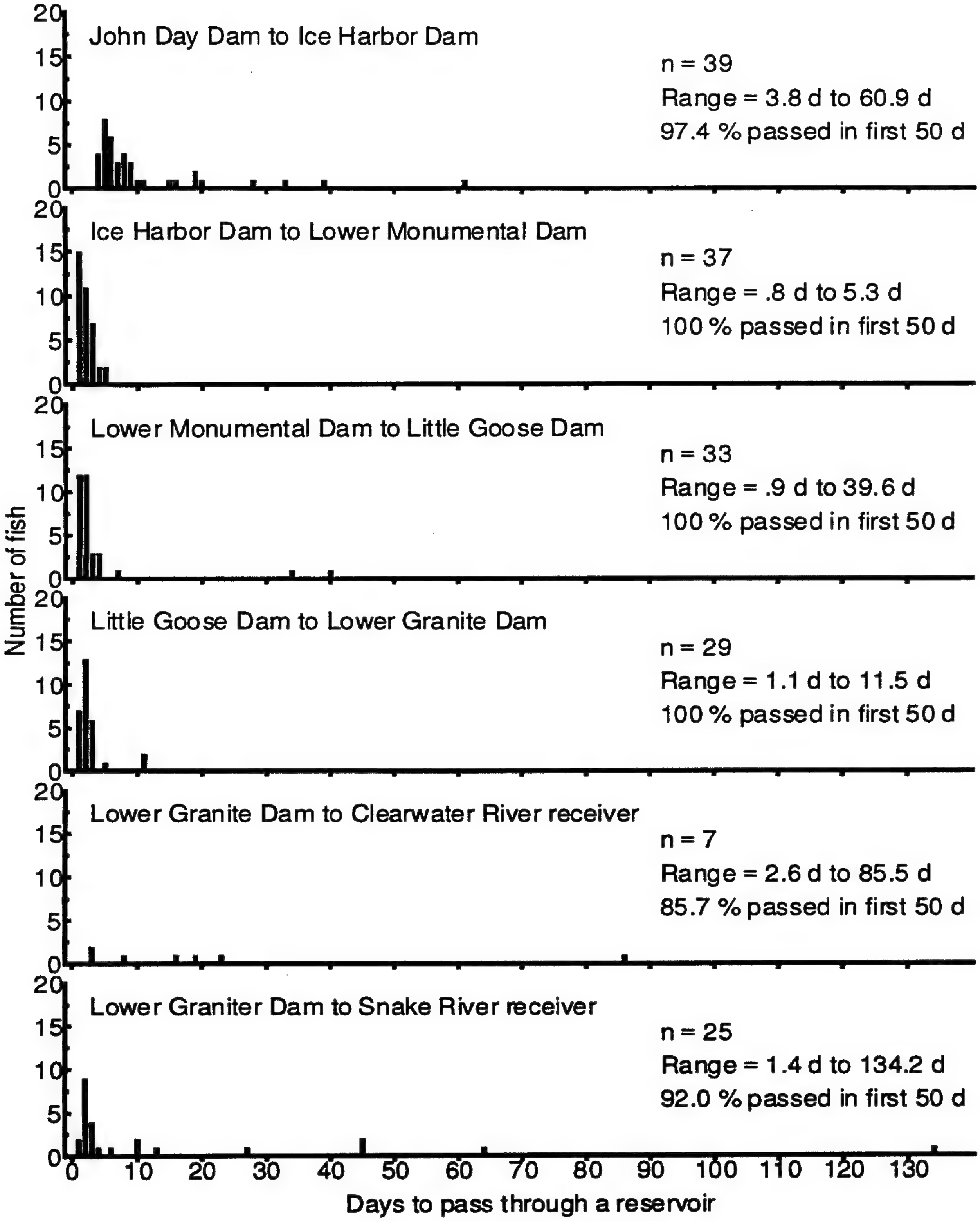


Figure 99. Frequency distribution of the time steelhead with transmitters took to pass through lower Snake River reservoirs in 1993. Steelhead released at John Day Dam in July and August that crossed over Lower Granite Dam before 31 December 1993.

the Tucannon River, 5 were taken in traps, 1 was found dead, and 10 transmitters were found along the river.

Twenty-two tagged steelhead were reported taken by anglers from the Snake River between Lewiston and the Salmon River, 3 fish were taken from the Snake River upstream from the Salmon River, and 25 were trapped at Hells Canyon Dam, for a total of 50 fish (8.4% of the recaptures, Table 13).

In the Clearwater River basin, 49 tagged steelhead were reported caught from the main stem Clearwater River, and 2 from the North Fork (Table 13). In addition, 51 of the tagged steelhead entered Dworshak NFH and 8 tagged steelhead entered Kooskia NFH for a total of 110 fish (18.5% of the recaptures).

Forty-two steelhead (7.0% of recaptures) were reported as recaptures in the Grande Ronde River basin with 10 taken in the fishery, 3 in traps and 29 into hatcheries (Table 13). Six (1.0% of the recaptures) recaptured steelhead were reported trapped at the Little Sheep Creek weir in the Imnaha River basin.

Anglers fishing the Salmon River basin reported catching 54 tagged steelhead, 10 fish were found during electro-fishing surveys, 1 was found dead, 1 transmitter was found, 1 tagged steelhead was taken at Rapid River SFH, 23 were taken at Pahsimeroi SFH, and 4 at Sawtooth SFH, for a total of 94 recaptures (15.8% of recaptures, Table 13).

In 1993, 20.8% of the 884 steelhead released with transmitters were wild fish and the remainder were classified as hatchery fish on the basis of fin clips. Of 204 steelhead with transmitters reported by anglers as being caught, 20 (9.9%) were wild fish of which 10 were kept, 8 were released, and the disposition of 2 fish was unknown. Of the 184 hatchery steelhead with transmitters reported caught by anglers, 175 were kept, 5 were reported released, and the disposition of 4 fish was unknown.

Steelhead released with spaghetti-loop tags for the zero-flow test in 1993 were also caught by anglers, but they were all hatchery fish. Of the 125 fish reported caught, 115 were kept, 2 were released, and the disposition of 8 fish was unknown.

Fish that had been tagged and were later recaptured upstream from Lower Granite Dam could be identified if they had a transmitter, had retained the VI tag, and for a lesser number if they had a jaw tag or a spaghetti-loop tag. Only a small number of jaw tags were used in 1993 and spaghetti-loop tags were removed from all fish recaptured in the Lower Granite trap. Anglers reported to us the catching of 147 steelhead upstream from Lower Granite Dam that had been tagged in 1993. Eighty-two of the fish had VI tags recognized by the anglers, of which 8 had transmitters, 17 had spaghetti-loop tags, and 5 had jaw tags. Four of the fish caught had lost the VI tags and were identified by the

Table 13. Recaptures of the 884 steelhead with transmitters released at John Day Dam and the 1,994 fish tagged with spaghetti-loop tags and released at Charbonneau campgrounds near Ice Harbor Dam in 1993. Recaptures occurred from July 1993 through June 1994.

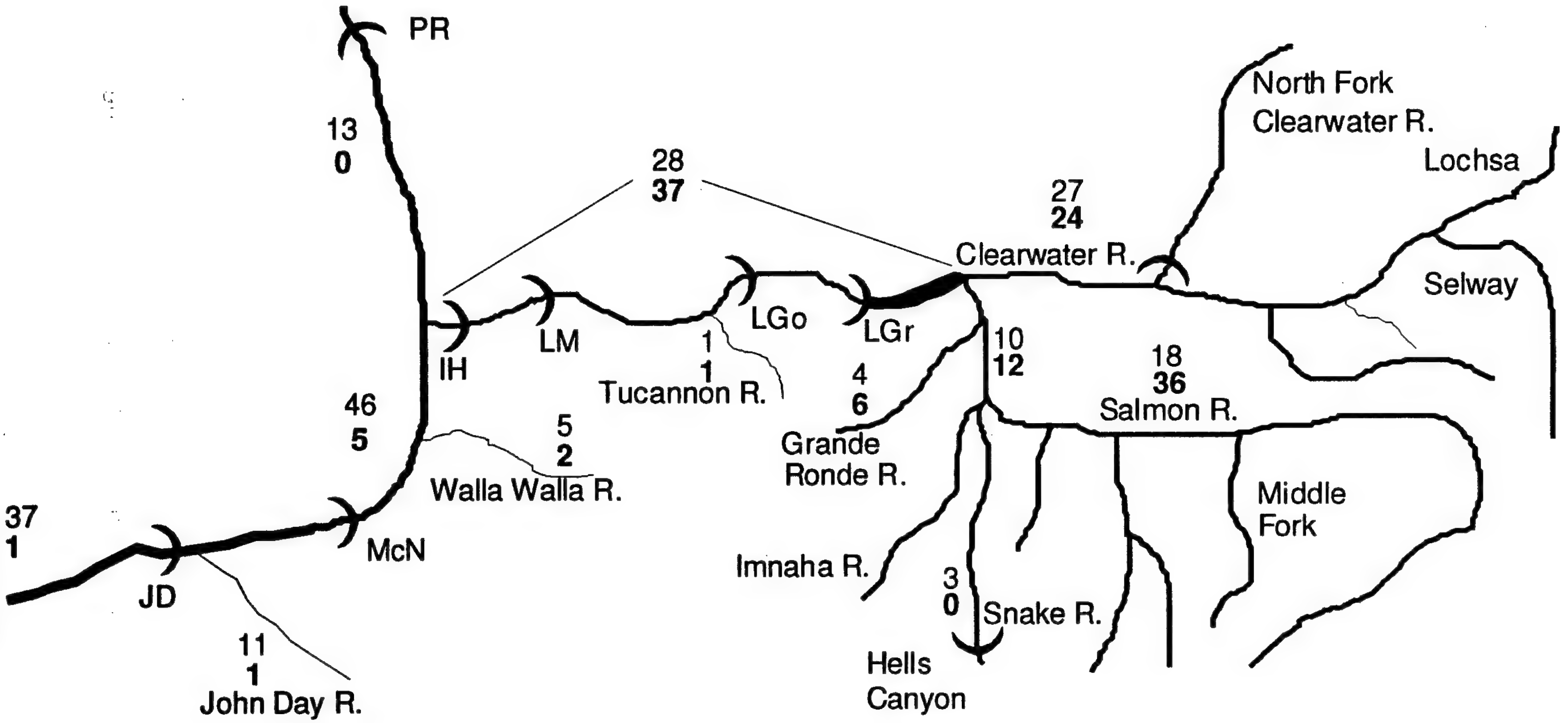
Recapture location	Type of recapture	John Day releases	Charbonneau releases
Unknown	Unknown	5	
Columbia River			
Downstream from Snake River			
Downstream from John Day Dam	Fishery	24	
	Found transmitter	3	
Deschutes River	Fishery	13	1
	Found transmitter	3	
	Weir	1	
	Trap	1	
	Found dead	1	
John Day Dam to Snake River	Fishery	46	5
	Found transmitter	1	
	Found dead	1	
at John Day Dam	Found transmitter	14	
	Weir	4	
John Day River	Fishery	11	1
	Found transmitter	1	
Umatilla River	Weir	6	
	Found transmitter	1	
Walla Walla River	Fishery	4	1
Touchet River	Fishery	1	1
Upstream from Snake River	Fishery	8	
	Found transmitter	4	
Priest Rapids Dam	Found transmitter	1	
Wenatchee River	Fishery	1	
Wells Hatchery	Hatchery	2	
Methow River	Fishery	1	
Okanogan River	Fishery	3	
Snake River			
Mouth to Lewiston	Fishery	28	37
	Weir	4	1
	Found transmitter	1	
	Found dead		1
Lyons Ferry Hatchery	Hatchery	2	38
	Found transmitter	5	
Tucannon River	Fishery	1	1
Lower Granite Adult Trap	Trap	336	1,463
Lewiston to Salmon River	Fishery	10	12
Salmon River to Hells Canyon Dam	Fishery	3	
Hells Canyon Dam	Trap	6	19

Table 13. Continued.

Recapture location	Type of recapture	John Day releases	Charbonneau releases
Clearwater River	Fishery	27	22
North Fork	Fishery		2
Dworshak Fish Hatchery	Hatchery	37	14
Kooskia Fish Hatchery	Hatchery	3	5
Grande Ronde River	Fishery	3	
Cottonwood Creek	Trap	1	2
Wallowa River	Fishery	1	6
	Hatchery	5	11
Big Canyon Creek	Hatchery	2	11
Salmon River	Fishery	14	32
	Found dead	1	
	Found transmitter	1	
	Electro-shocking		1
Little Salmon River	Fishery	3	4
Rapid River	Trap	1	
Middle Fork Salmon	Fishery	1	
Carmen Creek	Electro-shocking	1	2
Rattlesnake Creek	Electro-shocking	1	1
Warm Springs Creek	Electro-shocking		1
Hat Creek	Electo-shocking		2
Pahsimeroi Fish Hatchery	Hatchery	5	18
Morgan Creek	Electro-shocking		1
Sawtooth Fish Hatchery	Hatchery		4
Imnaha River			
Little Sheep Creek	Trap	2	4

presence of spaghetti-loop tags (3 fish) or a jaw tag. Sixty-one of the captured fish were identified by the presence of either transmitters (47 fish), spaghetti-loop tags (10 fish), and jaw tags (10 fish), and the anglers did not notice if a VI tag was present.

Of the steelhead tagged in 1993, 150 were recaptured at hatcheries, traps or weirs upstream from Lower Granite Dam. Four (3%) of the recaptured fish had lost their VI tags and were identified by the presence of either a spaghetti-loop tag (3 fish) or a transmitter. Another 118 of the recaptured fish had retained their VI tags (retention rate = 118/122 = 0.97), with 26 of the fish also having transmitters, and 17 having spaghetti-loop tags. The remaining 28 recaptured steelhead were reported as having transmitters (23 fish), spaghetti-loop tags (3 fish), and a jaw tag, but there was no report on the presence or absence of VI tags.



Tagged: 884 at John Day Dam
1,994 at Ice Harbor Dam

Figure 100. Map of portions of the Columbia and Snake river basins with the location of reported recaptures of steelhead with transmitters re;eased at John Day Dam or spaghetti-loop tags (bold numbers) that were released near Ice Harbor Dam in 1993 and recaptured by anglers through the spring of 1994.

Ten steelhead tagged in 1993 were recaptured during electro-fishing surveys in the Salmon River drainage. Eight of the fish had retained their VI tags, and the two that had lost VI tags were identified by the presence of a transmitter and a spaghetti-loop tag.

Distribution of steelhead outfitted with transmitters in 1993

The 884 Steelhead outfitted with transmitters in 1993 were tracked as they migrated past the dams and into the tributaries of the Snake River through the end of the spawning period in May of 1994. The distribution of those fish based on last sitings at fixed-site receivers, by mobile tracking, and by recaptures by anglers, at weirs and hatcheries is presented in Table 14. Twenty-six of the 884 (2.9%) fish released with transmitters were not located again after release.

One hundred and seventy-nine (20.2%) of the released fish were last located downstream from John Day Dam in the Columbia River or in tributaries (Table 14), and 163 (18.4%) steelhead were last located in the Columbia River or in tributaries between John Day Dam and the Snake River. Thirty-eight (4.3%) of the fish were found in the Columbia River or tributaries upstream from the Snake River.

Within the Snake River, 17 of the steelhead were last recorded downstream from Ice Harbor Dam, and another 20 were last recorded at the dam or in the reservoir upstream from the dam. Lower Monumental Dam and Reservoir were the sites of last recordings for 25 steelhead, Little Goose Dam and Reservoir for 13 fish, and Lower Granite Dam and Reservoir for 67 fish (Table 14). One fish was located in the Tucannon River and seven entered Lyons Ferry Hatchery. A total of 189 steelhead (21.4% of those released) were last located in the lower Snake River, downstream from the receiver sites on the lower Clearwater River, and Snake River upstream from Lewiston. Several of the fish were harvested by anglers.

Of the 272 steelhead last located upstream from Lower Granite Reservoir, 123 (45.2%) entered the Clearwater River, and 149 proceeded up the Snake River upstream from Lewiston (Table 14). Of those last recorded in the Clearwater drainage, 37 entered Dworshak NFH, 3 entered Kooskia NFH, 2 were last recorded in the North Fork, 3 in the South Fork, 5 in the Lochsa River basin, 2 entered the Selway River, 1 was last recorded in Lapwai Creek, 14 fish were last located at the fixed site receiver near the mouth of the Clearwater River, and the remainder of the last sitings were scattered along the main stem (56 fish).

Of the 149 steelhead that migrated up the Snake River, 61 were last sited in the Snake River from Lewiston upstream to Hells Canyon Dam, 22 entered the Grande Ronde drainage, 2 entered the Imnaha River, and 64 entered the Salmon River (Table 14). Within the Salmon River drainage, 37 of the steelhead were last recorded in the

Table 14. Distribution of 884 steelhead released with transmitters in 1993 at John Day Dam based on last sitings at receivers or by mobile tracking, and recaptures by anglers, at weirs, or at hatcheries.

Location of last siting	Number of fish	Percent of recaptures
Columbia River		
Downstream from John Day Dam	127	14.4
Hood River	1	0.1
Deschutes River	51	5.8
John Day Dam to the Snake River	82	9.3
John Day Dam	79	8.9
John Day River	39	4.4
Umatilla River	7	0.8
McNary Dam	25	2.8
Walla Walla River	7	0.8
Touchet River	3	0.3
Upstream from the Snake River	27	3.1
Yakima River	3	0.3
Priest Rapids Dam	2	0.2
Wenatchee River	1	0.1
Wells Hatchery	2	0.2
Methow River	1	0.1
Okanogan River	2	0.2
Lower Snake River		
Downstream from Ice Harbor Dam	17	1.9
Ice Harbor Dam and Reservoir	20	2.3
Lower Monumental Dam and Reservoir	25	2.8
Lyons Ferry Hatchery	7	0.8
Tucannon River	1	0.1
Little Goose Dam and Reservoir	13	1.5
Lower Granite Dam and Reservoir	17	1.9
Lower Granite adult trap	50	5.7
Lewiston to the Salmon River	31	3.5
Receiver site near Asotin	21	2.4
Salmon River to Hells Canyon Dam	3	0.3
Hells Canyon Dam	6	0.7
Clearwater River drainage		
Receiver site near mouth	14	1.6
Clearwater River, mouth to North Fork	52	5.9
Lapwai Creek	1	0.1
Clearwater River, North Fork to Lowell	4	0.5
North Fork of the Clearwater River	2	0.2
Dworshak National Fish Hatchery	37	4.2
South Fork of the Clearwater River	3	0.3
Kooskia National Fish Hatchery	3	0.3
Lochsa River	4	0.5
Crooked Fork	1	0.1
Selway River	2	0.2

Table 14. Continued.

Location of last siting	Number of fish	Percent of recaptures
Grande Ronde River drainage		
Receiver site near mouth	10	1.1
Cottonwood Creek	1	0.1
Wallowa River	9	1.0
Catherine Creek	1	0.1
Prairie Creek	1	0.1
Salmon River drainage		
Salmon River, mouth to Riggins	7	0.8
Receiver site at Riggins	11	1.2
Little Salmon River	5	0.6
Salmon River, Riggins to South Fork	7	0.8
Receiver at mouth of Middle Fork	4	0.5
Salmon River, Middle Fork to North Fork	5	0.6
Receiver at North Fork	7	0.8
Salmon River upstream from North Fork	11	1.2
Carmen Creek	1	0.1
Pahsimeroi River	5	0.6
East Fork of Salmon River	1	0.1
Imnaha River		
Little Sheep Creek	2	0.2

main stem from the mouth upstream to North Fork, 5 entered the Little Salmon River, 4 likely entered the Middle Fork, 11 were found in the Salmon River upstream from North Fork, and 7 were last recorded in streams upstream from North Fork.

Notes on Use of the VI Tag

Tagged steelhead that were captured at the Lower Granite adult trap were identified using the channel and code of transmitters, color of the spaghetti-loop tag, VI tag number, and jaw tag number. In 1993, 1,799 tagged steelhead were captured at the Lower Granite adult trap. NMFS personnel noted that 40 (2.2%) of the VI tags were difficult to read. Of those 40 fish, 16 had tissue growing over the VI tag, 12 had adipose tissue that had become cloudy and partially obscured the tag, 9 were "unreadable", 2 were bloody, and 1 had a VI tag that had rotated out of position.

Though only 40 VI tags were reported as being difficult to read, there appeared to be problems accurately reading the numbers on the tags on 157 (8.7%) of the 1799 tagged steelhead that were captured. Forty-six (29.3%) of the 157 tagged steelhead appeared to be inaccurately read at time of tagging or time of recapture, the VI tag number recorded at recapture did not match the VI tag number recorded at the time of tagging.

Twenty-three (14.6%) of the 157 fish were recorded at recapture with VI tag numbers that were never used. Fifty-two (33.1%) of the 157 fish with suspect VI tag numbers, had numbers that matched the color of spaghetti-loop tag used, but the fork length of the fish did not match the fork length recorded when the fish was tagged at Ice Harbor Dam (greater than five cm difference).

A majority of the 40 tagged steelhead that were reported as having VI tags that were difficult to read at the Lower Granite trap were captured there in the spring of 1994. It appears that problems with tissue deterioration, damage, and regeneration may increase the difficulty of reading VI tags with the length of time they are in place. In some instances the use of a magnifying glass made it possible to read VI tags that were otherwise illegible while still in the fish. While VI tags were more obviously difficult to read after several months in the fish, numerous errors did occur in the fall with relatively recently implanted tags. The VI tags are quite small (approximately 1 x 3 mm) and are difficult to read. A larger VI tag would reduce errors and could easily be accommodated by adult steelhead, however, larger sizes were not available.

Steelhead - 1993 Zero-Flow Test

The test to assess the effects of reducing flows at night to near zero in the lower Snake River on steelhead migrations was continued in September through November 1993. The effects of zero flow at night on steelhead in the lower Snake River were evaluated by monitoring the migrations of the fish with transmitters, and more importantly, the four groups of steelhead tagged with spaghetti-loop tags and released at Charbonneau Campground at the start of each of the four two-week periods with either zero or normal flow at night.

Methods - Steelhead with Spaghetti-Loop Tags

The zero-flow test began on 6 September in 1993 when river temperatures had declined enough that steelhead began to enter the Snake River in large numbers. The first two-week period ran from 6 to 19 September; flows were maintained at near zero at Lower Granite, Little Goose, and Lower Monumental dams from about 2300 to 0500 hr each night; and 480 fish were captured, tagged with both a spaghetti-loop (green color) and VI (visual-implant) tag, and released upstream from Ice Harbor Dam at Charbonneau Campground during the first six d of the period (Figure 101). The next three two-week periods alternated from normal flow at night, to zero flow at night, to normal flow. About 500 steelhead were tagged (different color for each period) and released at the start of each period.

The flows at night during the zero-flow portions of the test, were decreased at the three upper dams to near zero by shutting down all turbines (ladder flows, and lockages maintained a small flow at each dam) starting about 2300 hr and continuing until about 0500 hr for each two-week period (Figure 102). Normal flows consisted of nighttime flows of about 11.5 kcfs during each two-week period (Figure 103).

Migrations of the steelhead tagged for the zero-flow study were monitored by: (1) the people counting fish at all four dams (number of fish with each color of loop tag by day); (2) recaptures at the adult trap in the Lower Granite Dam ladder; (3) date, time, and location of recapture in the fisheries; (4) date and number recaptured at hatcheries from each group; and (5) the movements of fish with radio transmitters during the zero and normal flow periods.

Results - Steelhead with Spaghetti-Loop Tags

Several types of data on steelhead movements during the zero-flow test in the fall of 1993 have been summarized including the numbers of fish with spaghetti-loop tags counted at the counting windows of the three dams upstream from Ice Harbor Dam, the numbers of loop-tagged fish captured in the adult trap at Lower Granite Dam, and data

from the fish released with radio transmitters. Data on recaptures in the fisheries and at the hatcheries in 1991, 1992, and 1993 have been analysed and are presented in this report.

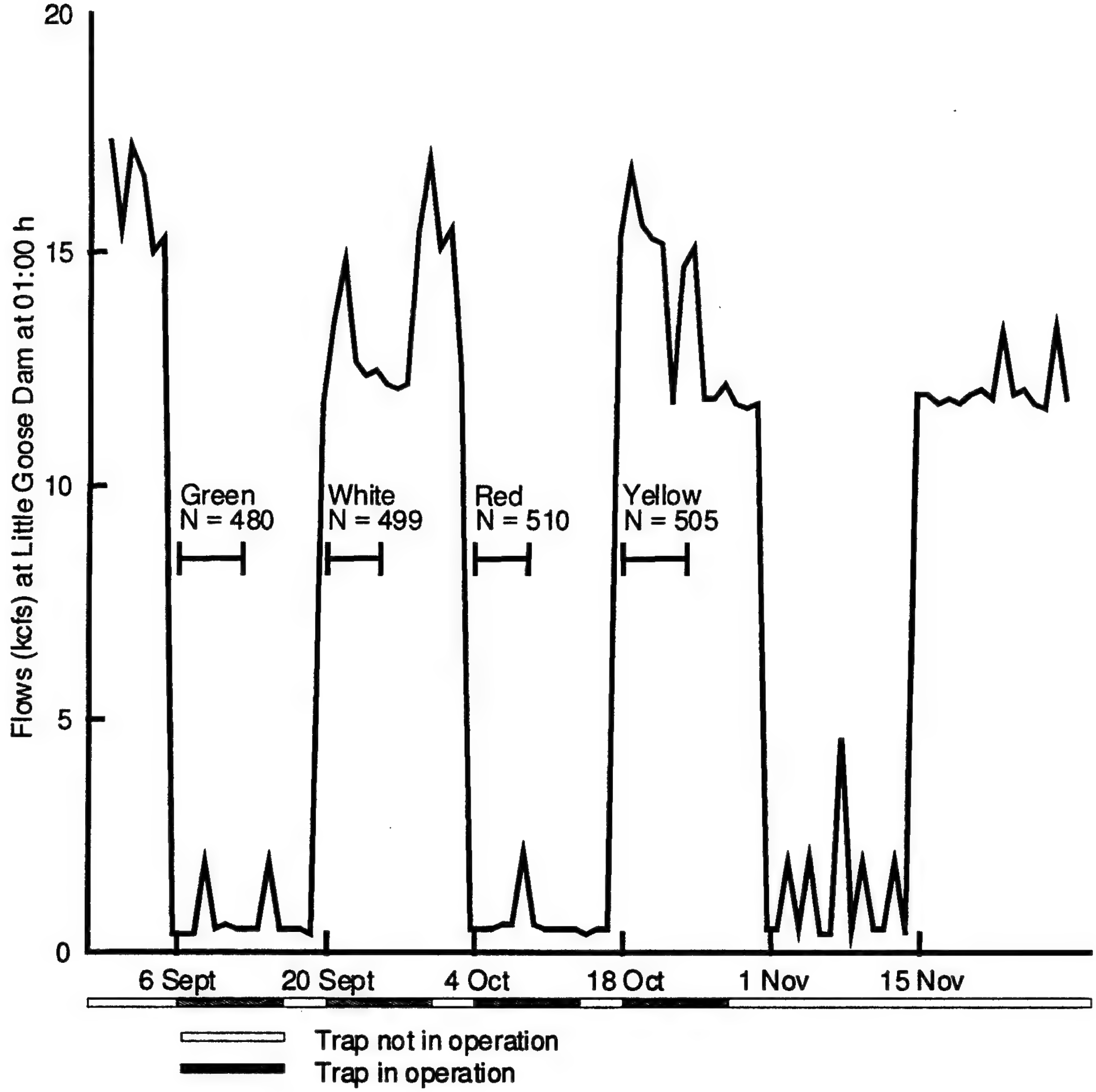


Figure 101. Pattern of flow at night at Lower Monumental Dam during the 1993 zero-flow test, the numbers of steelhead tagged with spaghetti-loop tags and released during the first five d of the four two-week test periods, and the color of tag used. Steelhead and chinook salmon were trapped the first 5 d of each two-week period, chinook salmon only during the second 5 d, and no trapping during the last 4 d.

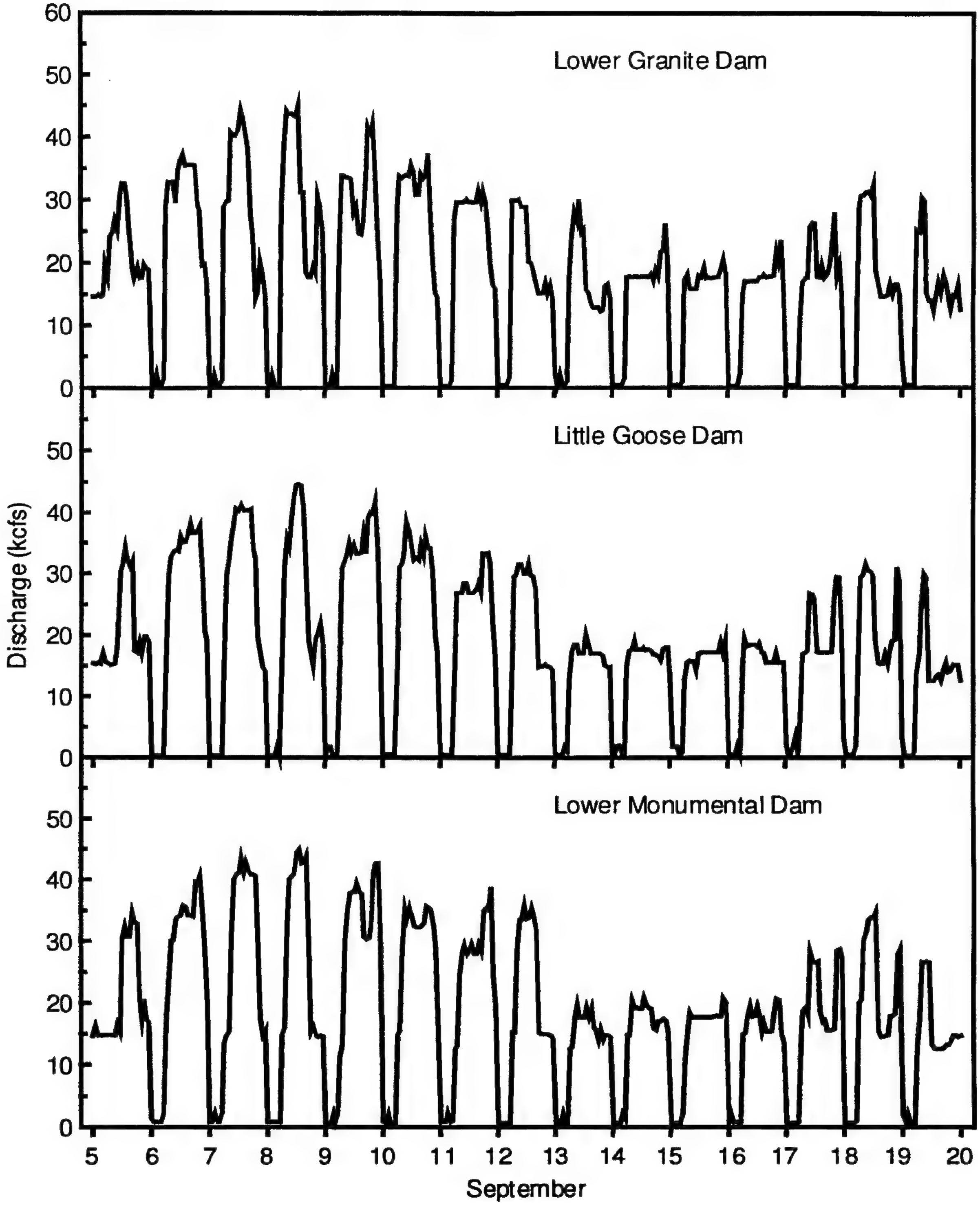


Figure 102. Discharges from the three upper dams in the lower Snake River during the two-week period from 6 to 20 September 1993 when flows were reduced to near zero from about 2300 to 0500 hr each night.

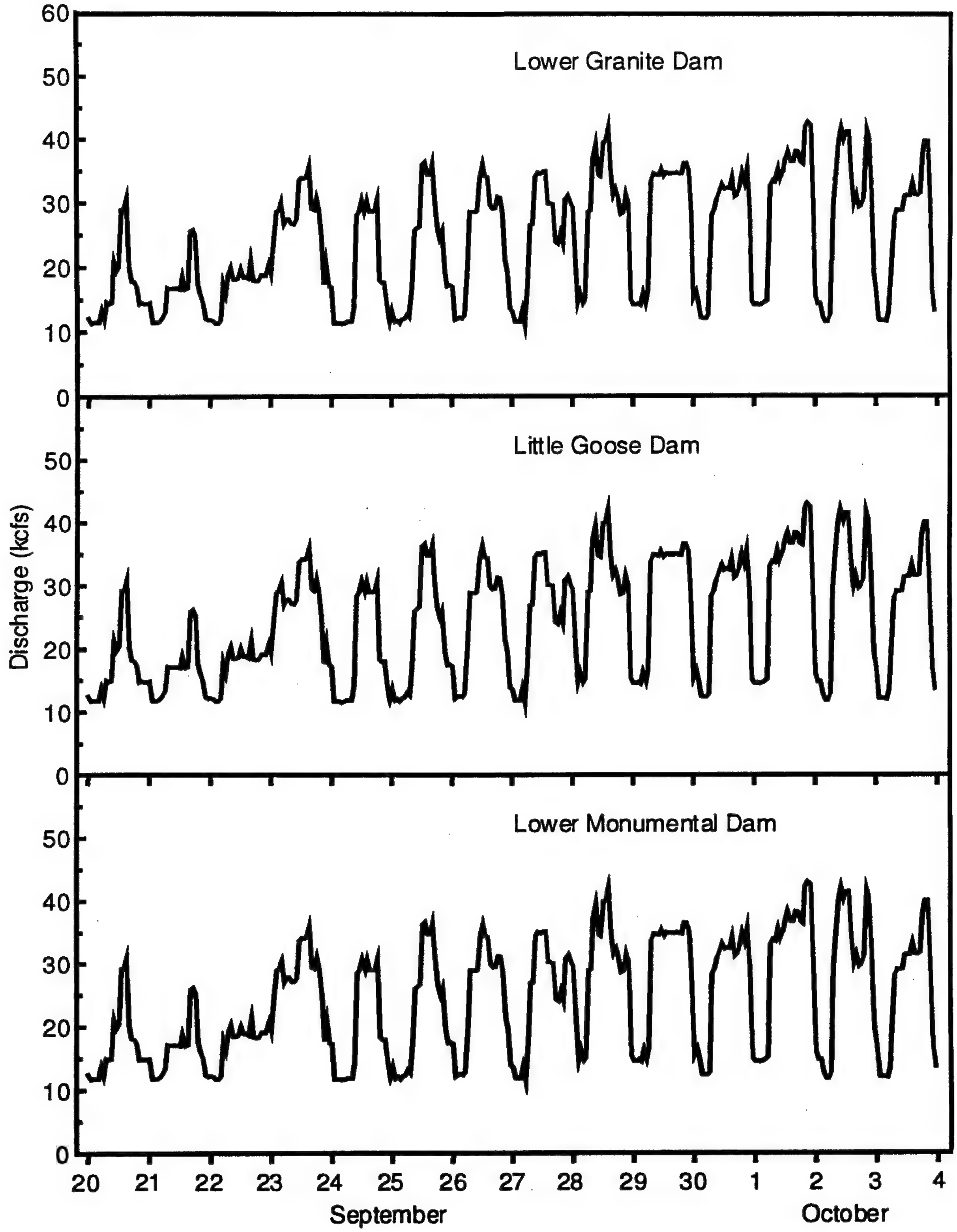


Figure 103. Discharges from the three upper dams in the lower Snake River during the two-week period from 21 September to 4 October 1993 when flows were maintained at a minimum of 11.5 kcfs from about 2300 to 0500 hr each night.

Fish counted at the dams

Steelhead in all four of the groups tagged with spaghetti-loop tags and released for the zero-flow study in 1993 moved upstream and passed over the three upstream dams with well defined peaks 3-5 d apart (Figure 104). Peak numbers of the first group (green tag) were counted at Lower Monumental Dam 6 d after release, at Little Goose Dam after 9 d, and at Lower Granite Dam after 10 d. Similar timing was observed for the second, third, and fourth groups released.

At Lower Monumental Dam, steelhead with the loop tags started passing and were recorded by the fish counters 1 or 2 d after the first releases (Figure 105). Fish for the first, second, third and fourth groups were counted for 85, 71, 57, and 43 d, respectively at Lower Monumental Dam. Despite the unequal number of counting days after release at Lower Monumental Dam, the data can be analyzed because most of the fish had passed the dam within 10 d of release (Figure 104). Mean and median days to pass Lower Monumental Dam and the percentage of fish released that were counted was based on the first 43 d of counting after release so the data would not be biased from the unequal periods of counting. The mean days to pass Lower Monumental Dam after release at Charbonneau Campground ranged from 4.9 to 9.8, and the median day of passage ranged from 4 d for the second and third groups to 7 d for the first group (Table 15).

At Little Goose Dam, fish counters started recording the passage of fish from all four groups 2-6 d after their respective releases (Figure 105). The minimum period of counting for any group at Little Goose Dam was 43 d, so the mean and median days to pass, and the percentage counted at the dam was based on the first 43 d after each release. The mean days to pass Little Goose Dam ranged from 7.5 d for the third group to 16.3 d for the first group (Table 15). The median day of passage ranged from 7 to 12 d.

Spaghetti-tagged steelhead began passing Lower Granite Dam 4 to 6 d after their respective releases (Figure 105). Counting of fish at Lower Granite Dam continued into December and the last group released was counted for 58 d, so estimates of mean and median days to pass and percentages counted were based on the first 58 d after each group was released. Mean days to pass Lower Granite Dam ranged from 10.5 for the third group to 19.4 for the first group (Table 15). The median day of passage ranged from day 10 to 15

The cumulative frequency distributions of fish passing each dam versus days after release illustrate some of the migration differences between the four groups of fish (Figure 106). The cumulative distributions for the second, third and fourth groups counted at Lower Monumental Dam appear similar. The first group (green tags) appears

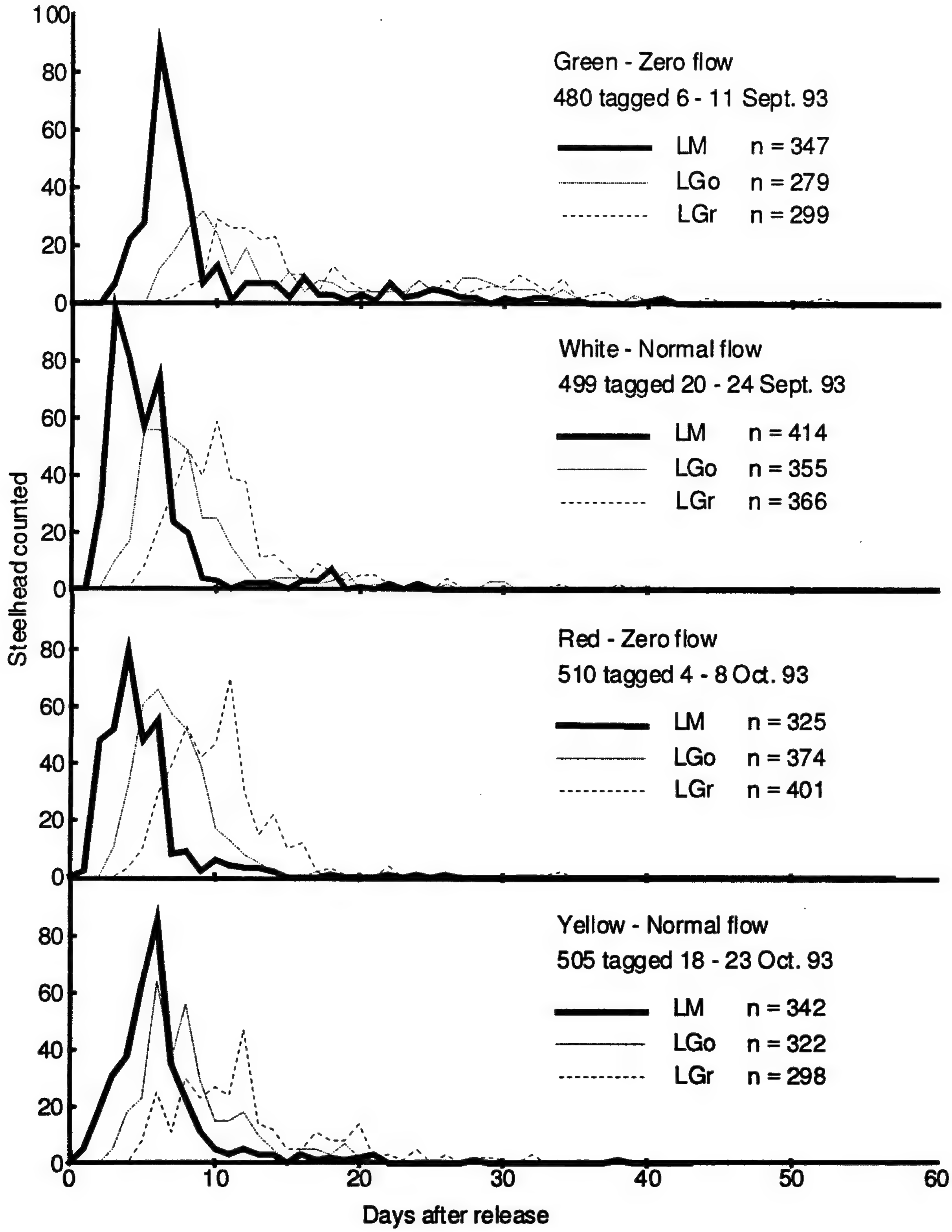


Figure 104. Frequency distribution of steelhead with spaghetti-loop tags that were counted at the three upper dams in the lower Snake River up to 60 d after release to illustrate the timing of each group of fish as they moved up the river in 1993.

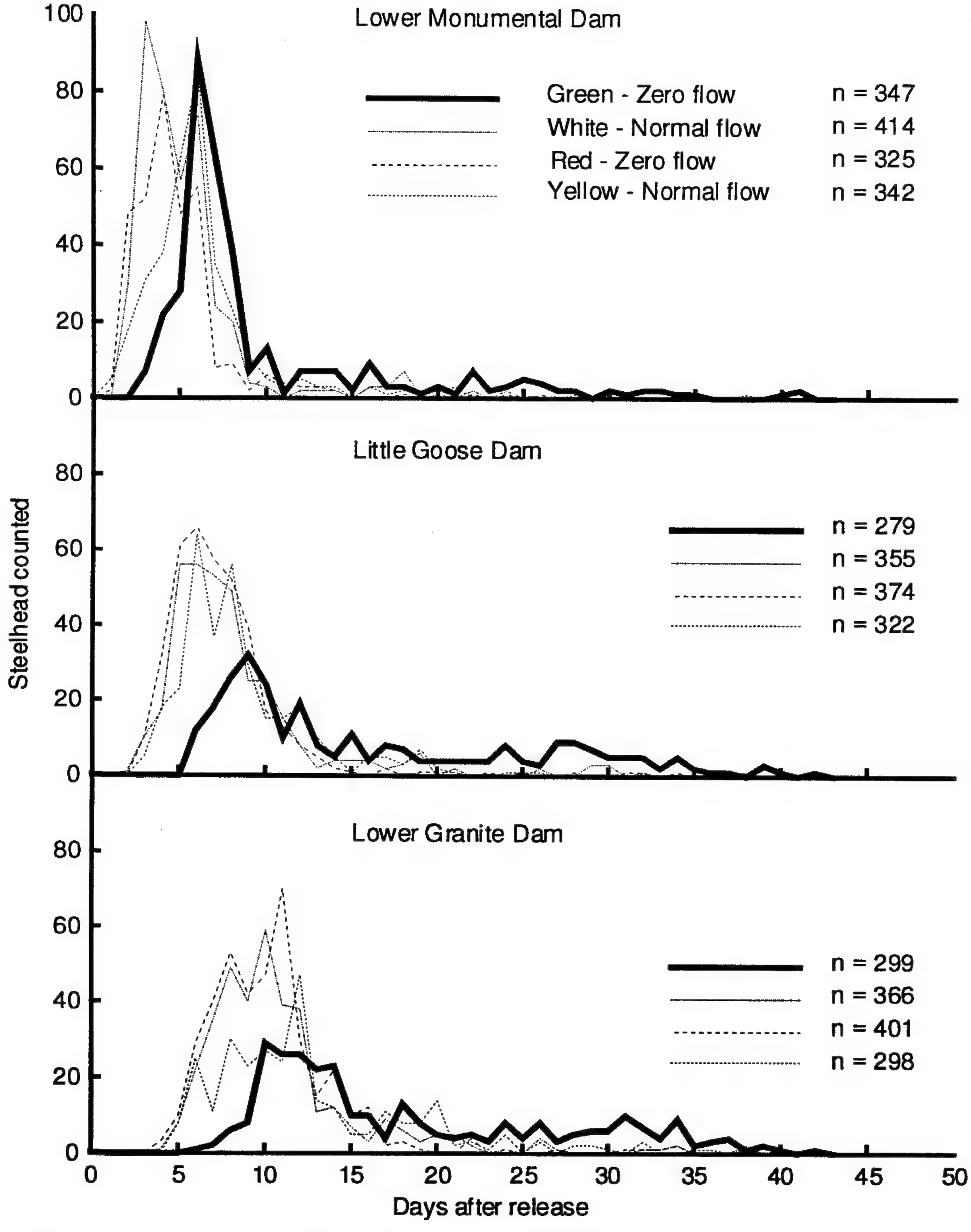


Figure 105. Frequency distribution of steelhead with spaghetti-loop tags that were counted at the three upper Snake River dams to illustrate the timing at each dam following the release of each group of fish in 1993.

Table 15. Mean and median days for steelhead to pass the three Snake River dams upstream from Ice Harbor Dam and percentage of fish released that were counted, based on counts of tagged steelhead passing the counting window for the four groups of spaghetti-loop tagged steelhead released for the zero-flow study in 1993. Estimates based on 43 d of counting after release for Lower Monumental and Little Goose Dams and 58 d of counting at Lower Granite Dam.

Group numbers Release dates Tag color	Flow at night	Lower Monumental Dam			Litttle Goose Dam			Lower Granite Dam		
		Mean (d)	Median (d)	Percent	Mean (d)	Median (d)	Percent	Mean (d)	Median (d)	Percent
Group1 6 - 11 Sep Green	Zero	9.8	7	72.3	16.3	12	57.3	19.4	15	62.1
Group 2 20 - 24 Sep White	Normal	5.3	4	83.0	8.5	7	70.7	11.1	10	73.3
Group 3 4 - 8 Oct Red	Zero	4.9	4	63.7	7.5	7	73.3	10.5	10	78.6
Group 4 18 - 23 Oct Yellow	Normal	6.3	6	67.7	8.7	8	63.8	12.8	12	59.0

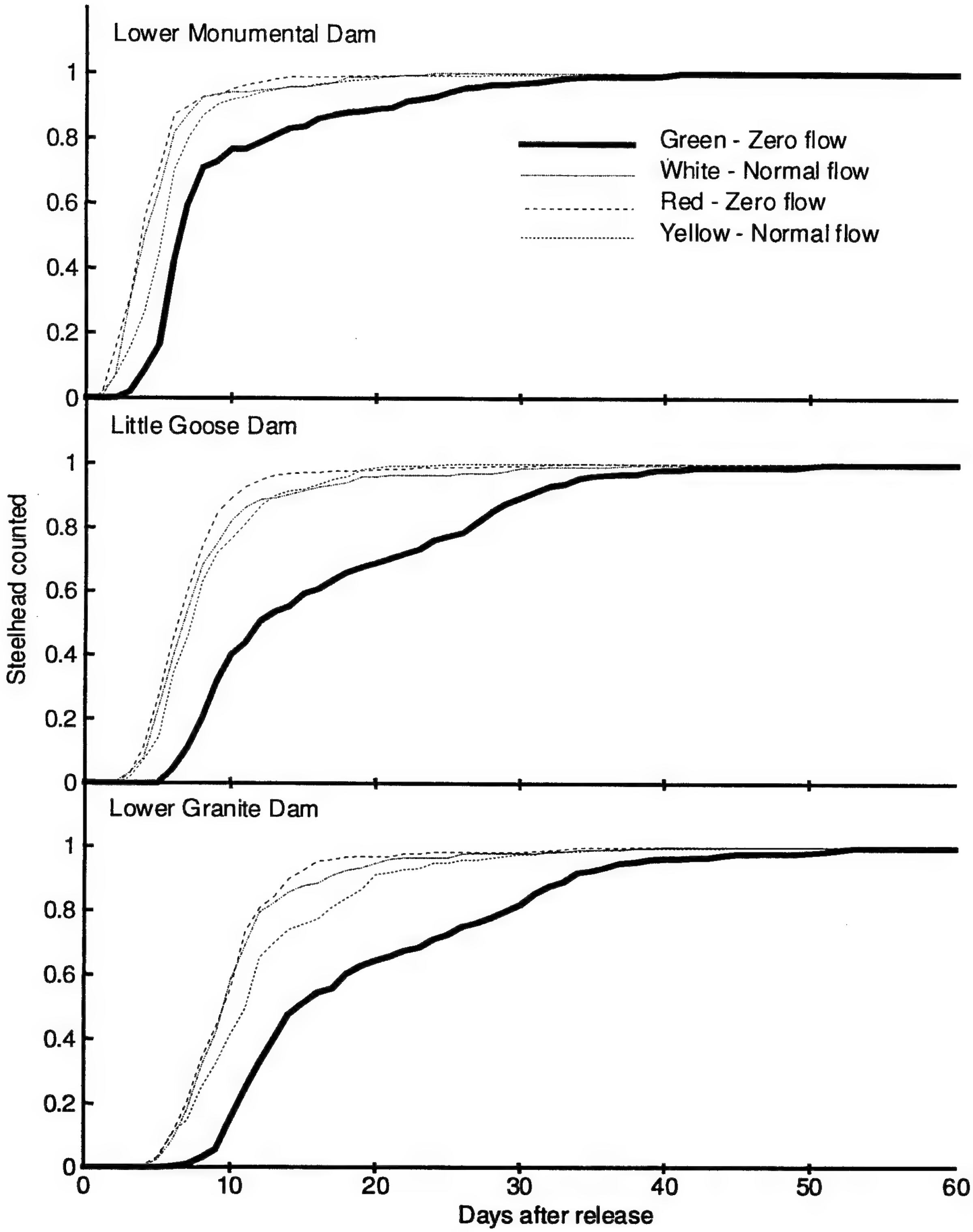


Figure 106. Cumulative frequency distribution of steelhead of each of the four groups tagged with spaghetti-loop tags, counted at the three upper Snake River dams in fall 1993.

to have migrated slower than the others. The same pattern was observed at Little Goose and Lower Granite Dams.

River temperatures declined steadily during the zero-flow study, as we expected, and may have been more of a factor in migration rates and behavior than other factors. In 1993, the order of periods with zero versus normal flow at night was the same as in 1991 and reversed from 1992 to determine if fish that enter the Snake River when temperatures are beginning to decline migrate at a slower rate than fish migrating two to four weeks later. Tagged fish from the first release group appeared to migrate at a slower rate than fish from the second release group in 1991, 1992, and 1993, regardless of flow at night.

The percentage of the fish released that were counted at the three dams is based on the minimum number of counting days for each dam as described earlier. The number of tagged steelhead from the four groups counted at Lower Monumental Dam amounted to 83% of the second group down to 63.7% of the third group (Table 15). At Little Goose Dam, the number counted was 73.3% of the third group and declined to 57.3% of the first group. At Lower Granite Dam, the counts amounted to 78.6% of the fish released in the third group and declined to 59.0% of the fourth group. The percentages of fish of each group counted have not been corrected for fallback that may have occurred at the dams, or for fish destined to enter the Tucannon River or Lyons Ferry Hatchery. In the spring of 1994, some fish from all four groups were counted at Lower Granite Dam, but the last group with the yellow tags were the most numerous.

Fish recaptured at Lower Granite Dam

Recaptures of fish with spaghetti-loop tags at the adult trap at Lower Granite Dam had the same patterns in terms of timing of recaptures as the counts of tagged fish in the fishways. Fish in the first group (green tags) released at Charbonneau Campground starting on 6 September began showing up at the Lower Granite trap 6 d later on 12 September, with the mode on the 11th d and median on the 14th day after the first day of release, and the mean at 16.3 d (Figure 107, Table 16). The peak numbers of recaptures (modes) were 11, 10, 11 and 12 d after release for groups 1 through 4, respectively. The last group was available for recapture for 32 d and so that was the period of trapping used to calculate the median and mean days to recapture for all groups. The median days to recapture at Lower Granite Dam ranged from the 10th for the second and third groups to the 14th for the first group. The mean days till recapture at Lower Granite Dam was lowest for the third group (10.1 d) and highest for the first group (16.3 d).

The percentage of each group of fish released for the zero-flow test that were recaptured at the Lower Granite adult trap ranged from a high of 78.2% for the third

group (red tags) to 52.9% for the first group (Table 16). These percentages are for the first 32 d of trapping after release of the respective groups, and they have not been corrected for any fallback that may have occurred at the dams or loss of tags, which was minimal.

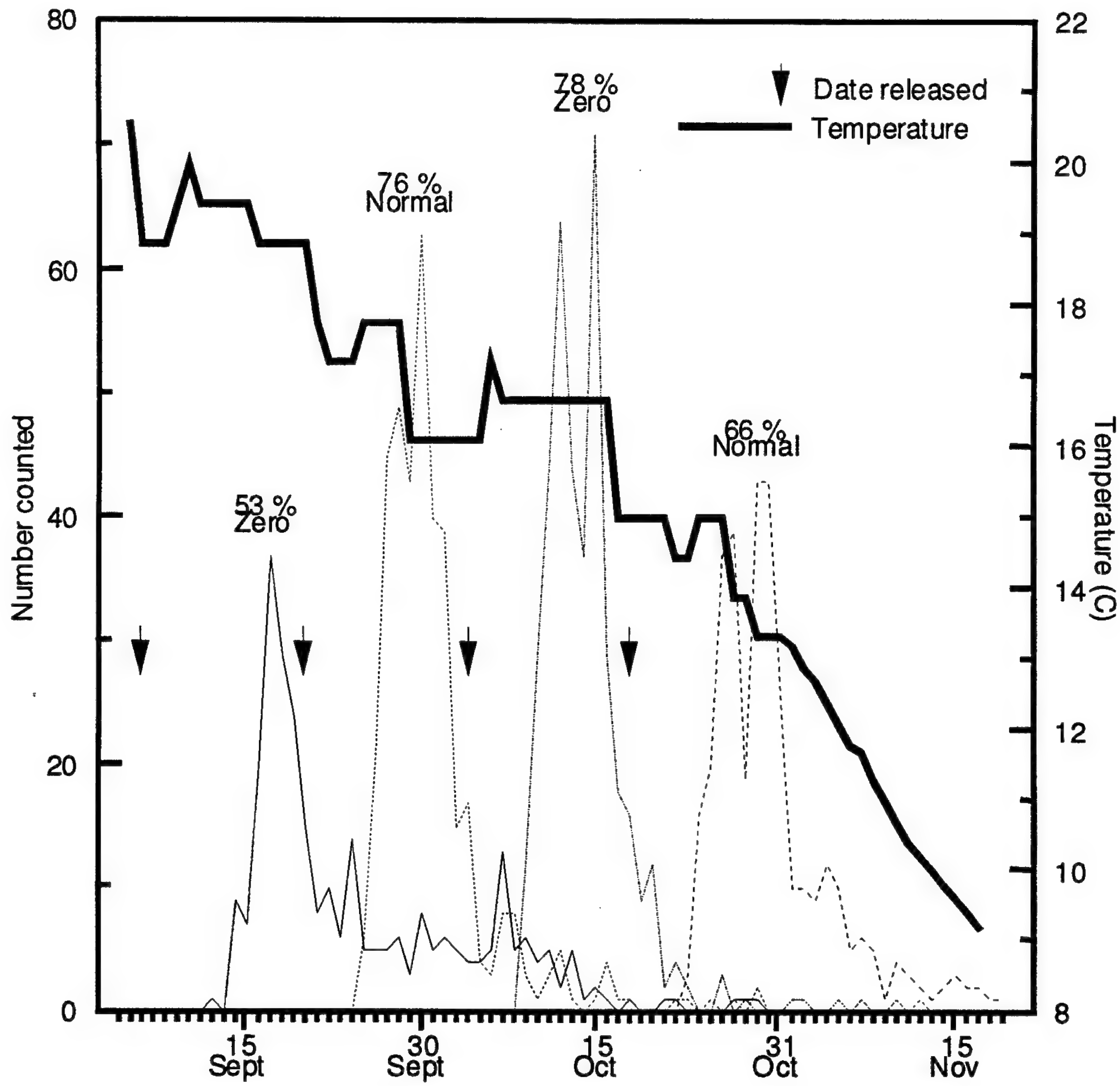


Figure 107. Timing of release at Charbonneau Campground and recapture at the Lower Granite trap of steelhead released with spaghetti-loop tags in each two-week period of normal or zero flow at night in the fall of 1993, with recaptures through the first week of December, and the temperature of the Snake River at the Ice Harbor Dam tailrace.

The pattern of recaptures of steelhead at the Lower Granite trap in 1993 (Figure 108) was similar to that observed in both 1991 and 1992. The highest percentages recaptured were fish in the second and third groups released, with smaller percentages recaptured from the first and fourth groups. Smaller percentages were recaptured in 1992 and 1993 than in 1991, partly because we used recaptures for the first 32 d following release in 1992 and 1993 (days after release of the last group that the trap was operated) versus the first 50 d in 1991. High river temperatures during the earlier part of the run, and declining temperatures during the latter part seem to be major factors in the rates of movement and percentages of fish in each group crossing over Lower Granite Dam in the fall. In 1993, as in previous years, we started the zero-flow test when there were enough steelhead crossing over Ice Harbor Dam to fulfill sample size requirements. The first periods started on 6, 8, and 16 September in 1993, 1992, and 1991, respectively.

Table 16. Mode, median, and mean days till recapture of steelhead at the Lower Granite adult trap that were tagged with spaghetti-loop tags and released at Charbonneau Campground during the zero-flow test in 1993. Data used was for the first 32 d after release of each group.

Group number Release dates Tag color (no. released)	Flow at night	Statistics for recaptures at adult trap (days after release)			Percent recaptured
		Mode	Median	Mean	
Group 1 6-11 Sep Green (480)	Zero	11	14	16.3	52.9
Group 2 20-24 Sep White (499)	Normal	10	10	10.7	76.4
Group 3 4-8 Oct Red (510)	Zero	11	10	10.1	78.2
Group 4 18-23 Oct Yellow (505)	Normal	12	11	12.3	66.1

So far in the testing, we have not found evidence that the migration of steelhead through the lower Snake River has been influenced by the zero-flow at night conditions created in the three lower reservoirs.

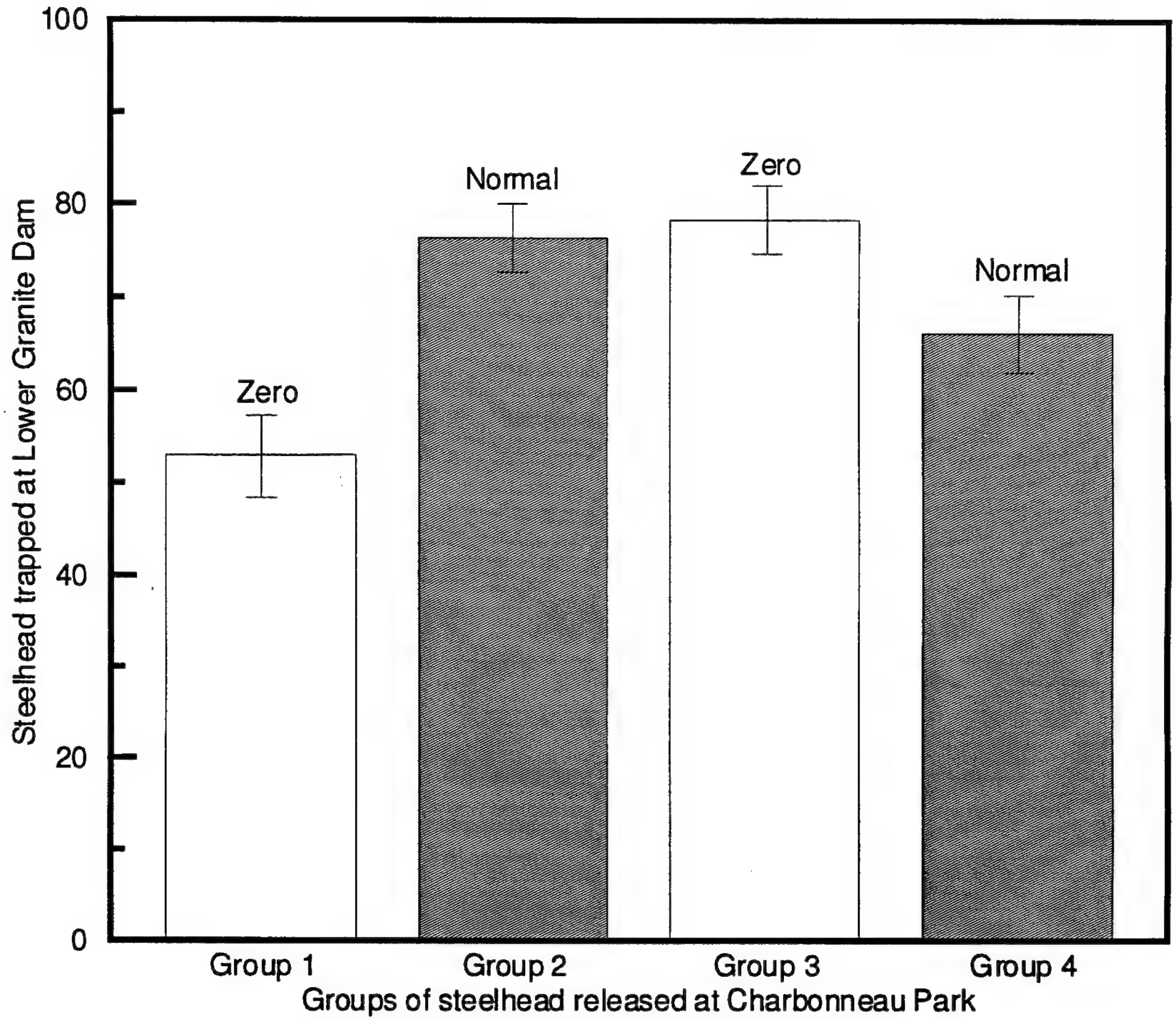


Figure 108. Percent recaptures (with 95% confidence intervals) at the Lower Granite trap of adult steelhead released with spaghetti-loop tags upstream from Ice Harbor Dam during the fall of 1993. Each group represents fish released at the start of a two-week period and recaptured for 32 d.

Recaptures at hatcheries and in fisheries

The proportion of fish with spaghetti-loop (or jaw tags) returning to hatcheries or being captured in the fisheries was similiar in 1991 and 1992 (Figure 109). In 1991, returns to hatcheries ranged from 3.2% to 7.5% of the fish released in the four groups, with the highest return from the first group. In 1992, returns to hatcheries ranged from 4.3% to 7.7%, with the highest return from the third group. Returns to the fisheries ranged from 19.9% to 26.3% for four groups released in 1991, and 15.8% to 25.9% in 1992, with the

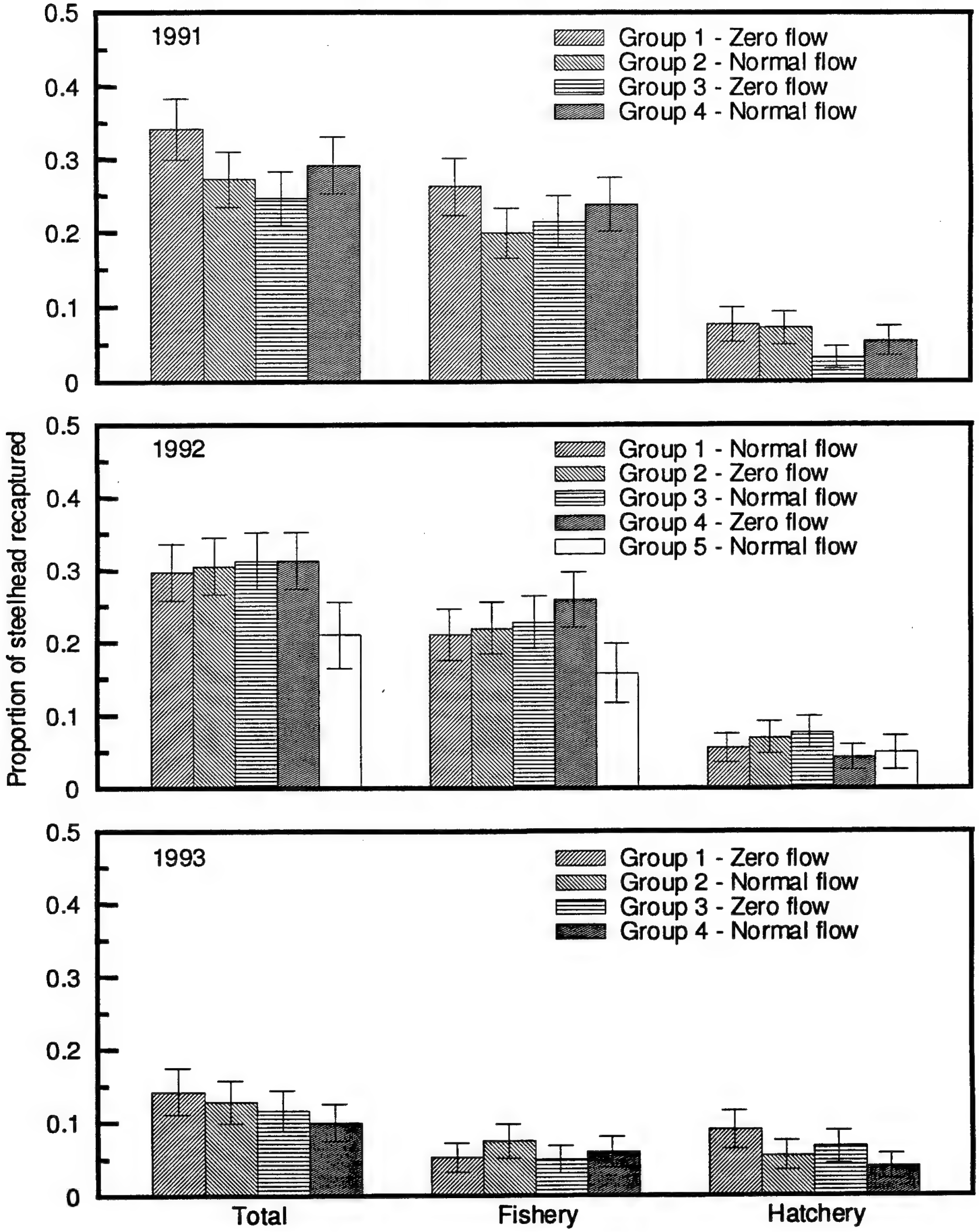


Figure 109. Proportions with 95% confidence intervals of steelhead exposed to zero or normal nighttime flows that were recaptured either in the fishery or at hatcheries in 1991, 1992, and 1993, with 95% confidence intervals.

highest returns from the first group in 1991 and the fourth group in 1992. Total returns from the third group released in 1991 were significantly smaller than those of the first group, but return rates for the other groups were not significantly different. In 1992, total returns for the first four release groups were not significantly different, but the rate for the fifth group was lower than the others primarily because of a lower return from the fisheries (Figure 109).

In 1993, returns to hatcheries were simliar to those observed in previous years ranging from 3.9% to 8.9%, with the highest return from the first release group. Returns from the fisheries were much lower in 1993 than the rates observed in 1991 and 1992 (Figure 109). Returns from the fisheries ranged from 4.0% to 9.0%, about one-fourth the rates in 1991 and 1992. Differences between the return rates from the fisheries and to hatcheries for the four groups released in 1993 were not statistically significant. One explanation for lower returns from the fisheries in 1993 was the use of visual-implant (VI) tags rather than jaw tags for secondary identification of a spaghetti-loop tagged fish. While jaw tags are quite obvious, an untrained observer could easily overlook a VI tag.

Methods - Steelhead with Transmitters - 1993

During 1993, 884 steelhead were outfitted with radio transmitters and released at John Day Dam. About 330 of those fish entered the Snake River, were recorded on the tailrace receiver at Ice Harbor Dam, and were potential candidates for analysis of movements during the zero-flow test, in addition to providing general information on steelhead movements within the Snake River basin.

The analysis of movements of fish with transmitters during the zero-flow test was conducted on a reservoir by reservoir basis. In order for an individual fish to be included in the analysis of fish movements through a reservoir under a particular flow regime, the fish had to be exposed to only one flow regime for the entire period of time that it was in the reservoir. Fish that entered a reservoir under one flow regime had to exit the reservoir prior to the beginning of the next flow regime in order to be included in the analysis of movements through that reservoir.

Migration times through reservoirs for fish with transmitters were calculated by subtracting the date and time for the last record for a fish at the top of a fish ladder at one dam from the date and time for the first record for that fish at the downstream (tailrace) receiver site at the next dam upriver. The distance between the receiver sites was then divided by the migration time to give a migration rate for an individual fish through the reservoir.

The zero-flow test began in 1993 on 6 September with a two-week period of zero flows at night, followed by two-week periods of normal, zero, normal, and zero flow (Figure 101). Steelhead were released with spaghetti-loop tags during the first four

two-week periods as reported in the preceeding section. Steelhead released at John Day Dam with radio transmitters during the fall migrated past the dams and through the Snake River reservoirs during all five of the two-week periods and data were analyzed and presented for the five periods.

Results - Steelhead with Transmitters - 1993

In the summer and fall of 1993, 884 steelhead were tagged with transmitters. Of those, 157 individuals were used in the zero-flow test for one or more reservoirs. The other 727 fish either did not migrate up the Snake River or failed to meet the criteria of being exposed to only one flow regime during their passage through any one reservoir.

Steelhead with transmitters that were analyzed for the zero-flow study in 1993 migrated through the lower Snake River reservoirs at rates ranging from a low of 4.5 km/d to a maximum of 67.5 km/d. On average, during the zero-flow test, fish with transmitters migrated though the lower Snake River reservoirs at about 27.9 km/d. As occurred in 1991 and 1992, there were small differences in migration rates for steelhead observed during different flow regimes (Figure 110) and in different reservoirs (Figure 111), but the differences were probably not due to the flow at night.

Migration rates of steelhead with transmitters through all three reservoirs influenced by the zero or normal flows at night did not differ significantly in 1993 (Figure 112), and do not appear to be related to the flows at night. Water temperatures during the fall appear to have more influence on migration rates than a reduction of flows at night to near zero.

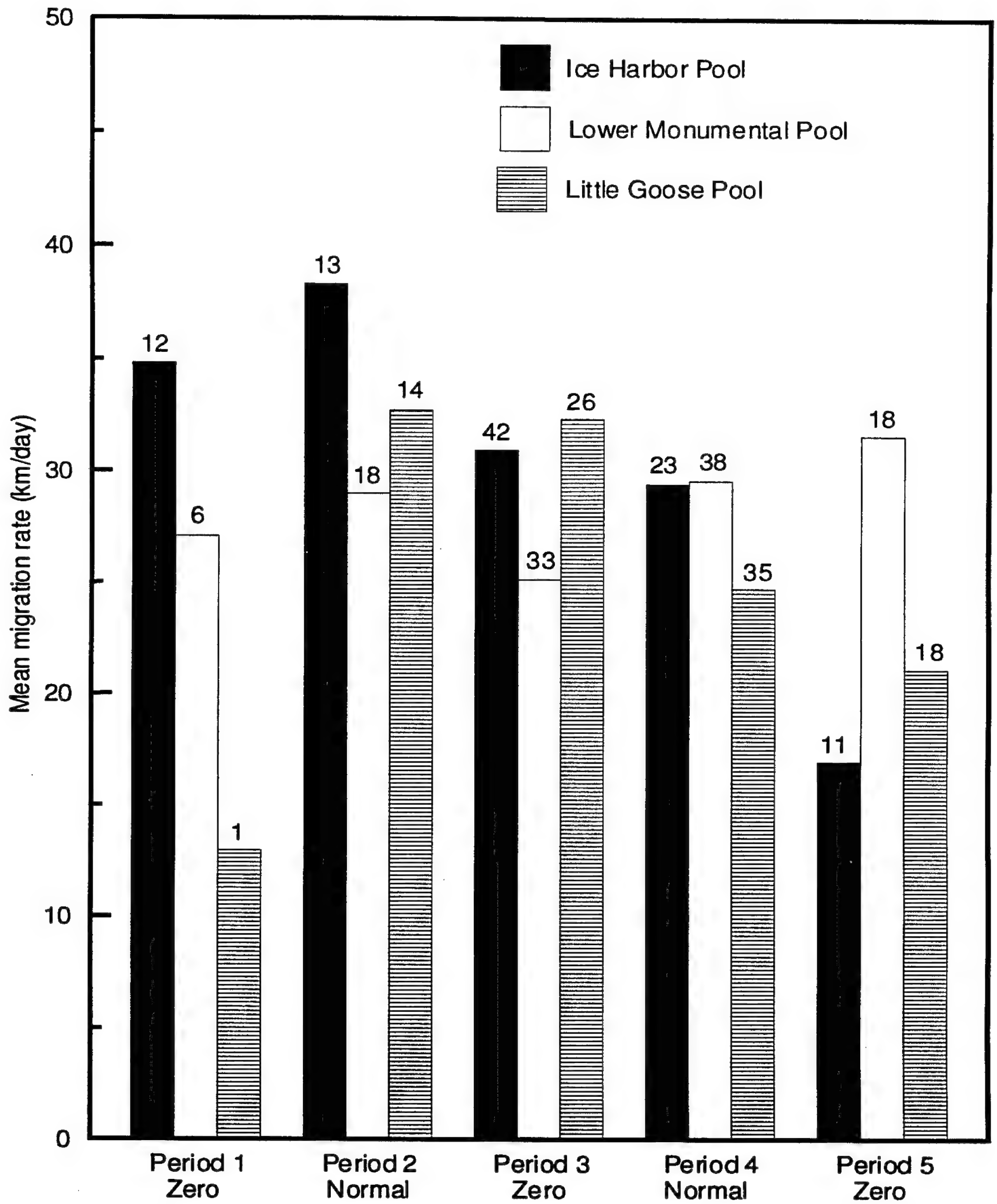


Figure 110. Mean migration rates of steelhead outfitted with transmitters in 1993 during periods of zero and normal nighttime flow in three of the lower Snake River reservoirs. Numbers on top of bars are number of fish monitored.

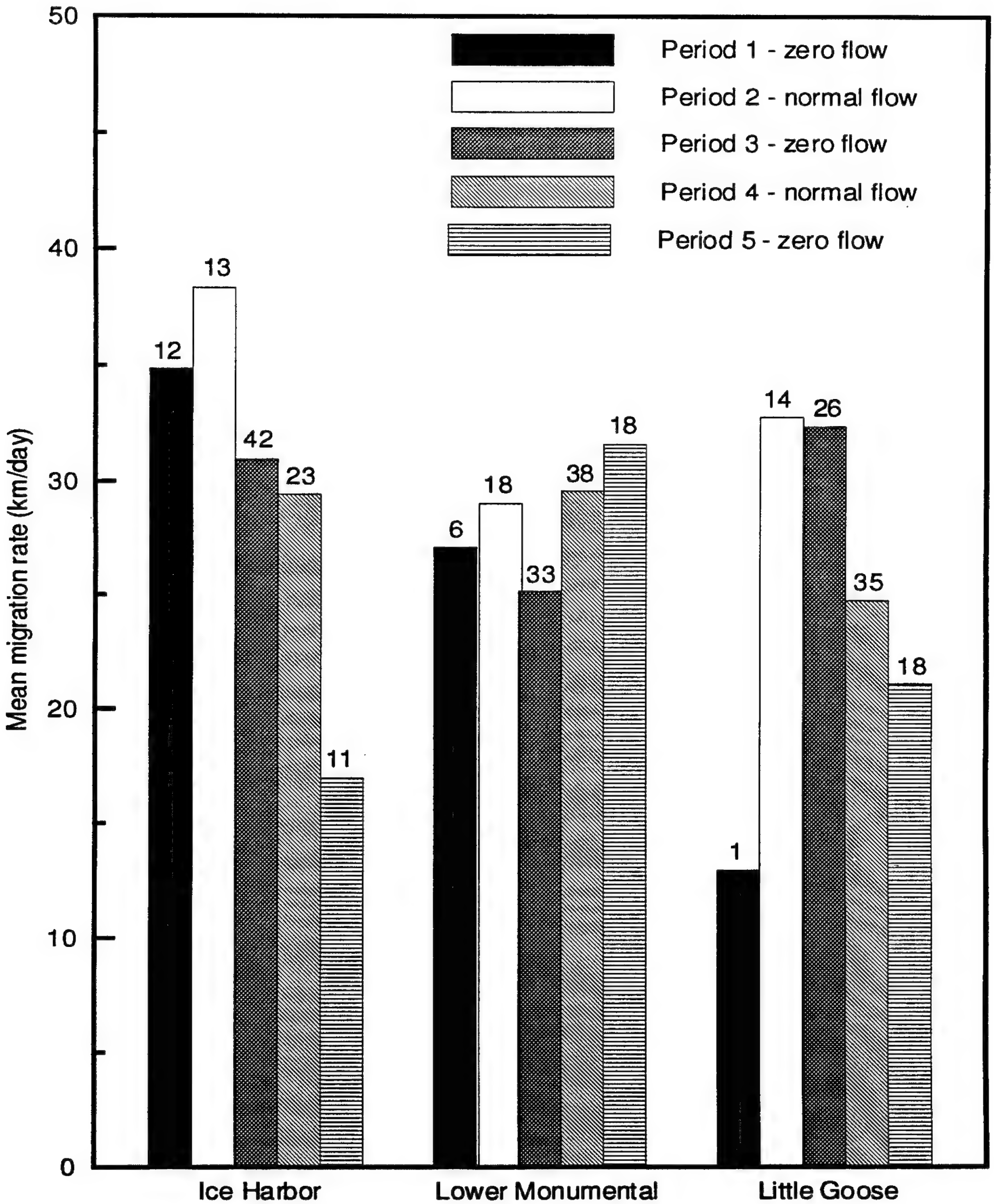


Figure 111. Mean migration rates of steelhead outfitted with transmitters as they migrated through three of the lower Snake River reservoirs during each period of the 1993 zero-flow test. Numbers on top of bars are number of fish monitored.

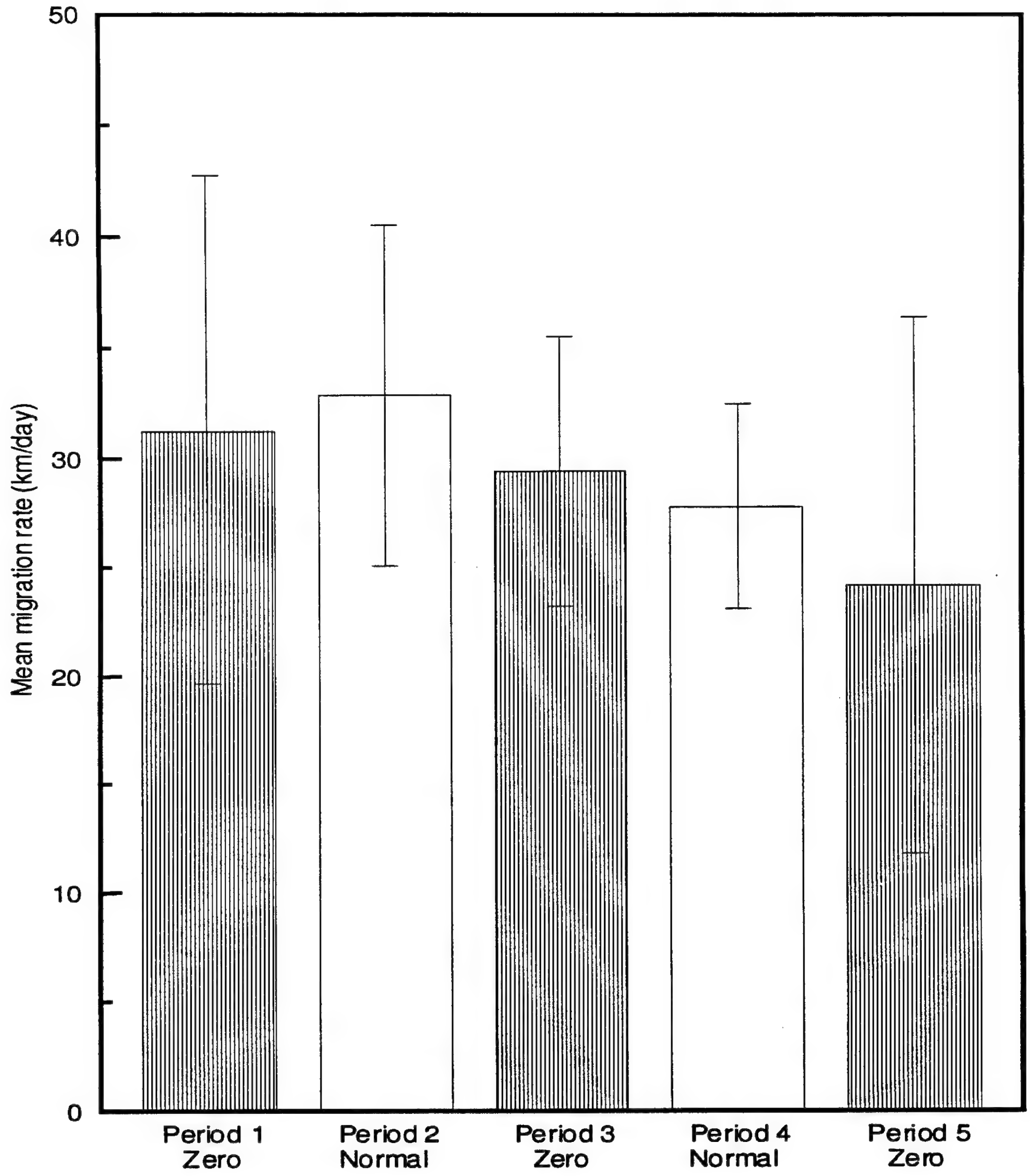


Figure 112. Mean migration rates of steelhead with transmitters through the three reservoirs (data combined) for the two-week periods influenced by the zero and normal flows at night in 1993. The vertical lines are the 95% confidence intervals.

Water Temperatures at the Dams

During 1993, as in 1991 and 1992, electronic temperature recorders were installed and maintained at the top of a fishway, at the lower end of the fishway (upstream from the supplemental flow inlets), and in the tailrace at each of the lower Snake River dams during the summer and fall. Water temperatures reached a peak of 21-23°C in mid August to early September in the lower Snake River (Figures 113 and 114). The discharge from the turbines (tailrace) was often 1-2° C cooler than water at the top of the fishway, or at the lower end of the ladders upstream from the supplemental water inlets. The water warmed as it moved from the top to the bottom of the Ice Harbor south-shore fishway during the hot sunny days of summer and fall.

In an attempt to maintain flows in the lower Snake River of about 50 kcfs to aid the seaward migration of fall chinook salmon smolts, up to nine kcfs of cool water (about 45°F) was released from Dworshak Dam from 2-9 July, and 12-20 kcfs from Dworshak and Brownlee reservoirs during the last half of July. The cool water releases may have had a slight effect on the tailrace temperatures at Lower Granite Dam through July (Figure 114). Reductions in temperatures of water discharged from Little Goose, Lower Monumental and Ice Harbor dams that could be attributed to the cool-water releases were not obvious (Figure 113 and 114).

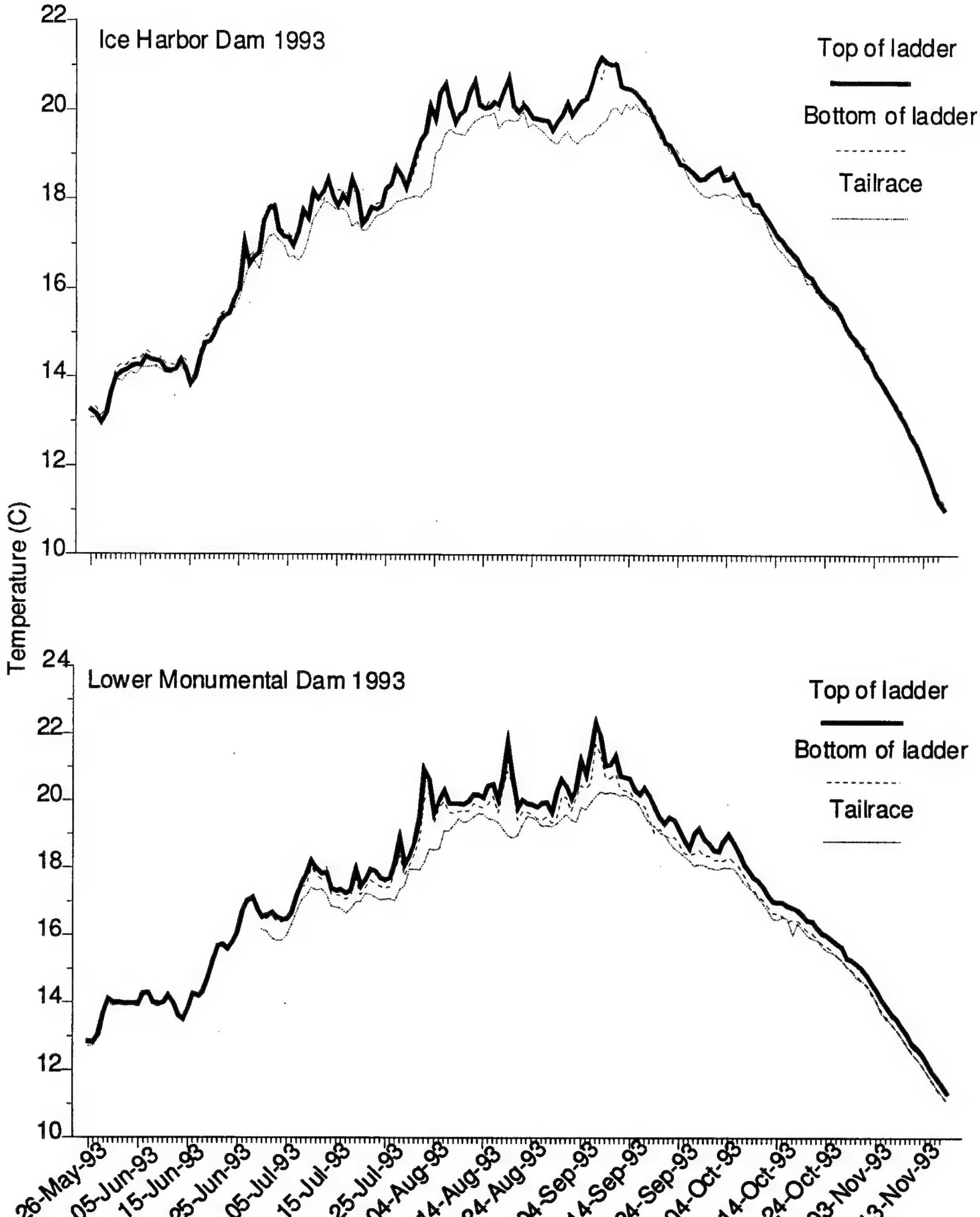


Figure 113. Water temperatures at Ice Harbor and Lower Monumental dams in 1993 at the top of the ladders, near the bottom of the ladders upstream from the supplemental flow inlets, and in the tailrace downstream from the dams.

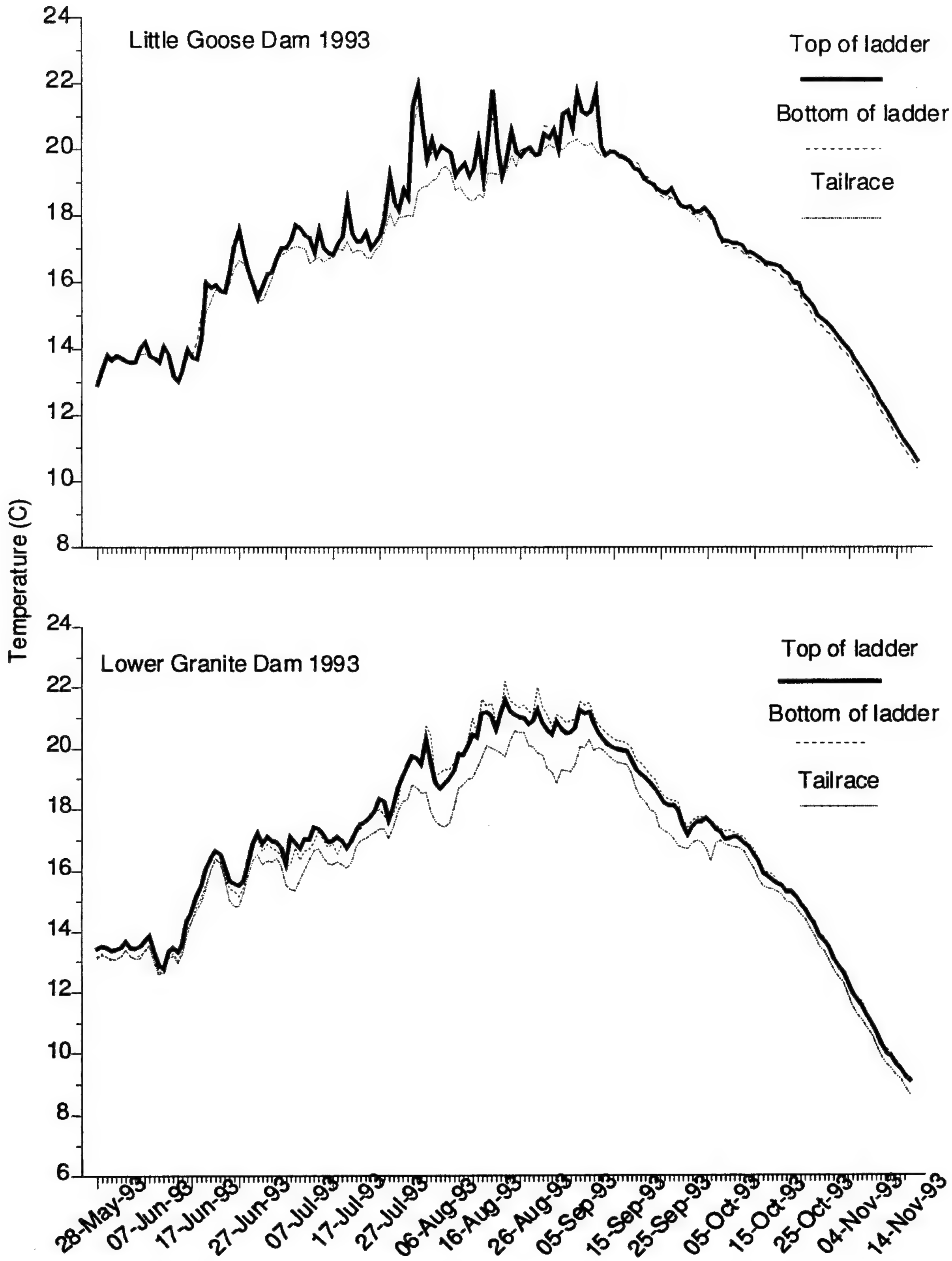


Figure 114. Water temperatures at Little Goose and Lower Granite dams in 1993 at the top of the ladders, near the bottom of the ladders upstream from the supplemental flow inlets, and in the tailrace downstream from the dams.

Spill, Dissolved Gas, and Salmon with Head Scrapes - 1993

During the spring of 1993, adult chinook salmon with a condition referred to as "head burns" were noticeably more abundant than in recent years at the Lower Granite adult trap, and prompted concern about the source of the injuries/disease. The "head burn" condition can range from scrapes and blisters on the head to loss of skin and fungus development on the head, and might be associated with gas bubble disease caused by supersaturation of gases in the water. The spring runoff in 1993 was large enough to cause significant amounts of spill at the lower Snake River dams for the first time in several years, and the dissolved gas monitoring stations set up by the Corps of Engineers in the forebays and tailraces of the dams provided an opportunity to gain more information on the relation between spill versus gas concentration. The tailrace dissolved gas monitoring stations were located 1-3 km downstream from the dams on the spillway side of the river. Adult chinook salmon captured at John Day Dam, outfitted with transmitters, and released in the fishway, migrated through the Columbia and lower Snake Rivers during the periods of spill so we could track the progress of individual fish in relation to the spill and exposure to supersaturated water.

Spill and Dissolved Gas Concentrations at the Dams

Spill at Lower Granite Dam occurred primarily during the latter half of May in 1993, with peak hourly spills of 181 kcfs during the nights of 17-19 May (Figure 115). The demand for power was low and virtually all the river flow was passed over the spillway on those three nights. Total dissolved gas (TDG) concentrations in the forebay at Lower Granite Dam were <110% of saturation throughout the runoff (Figure 115). The tailrace dissolved gas monitor failed soon after the period of spill began in mid May, but TDG concentrations had increased to the 115% of saturation level. Spill volumes of about 50 kcfs (about one-third of the river flow) produced TDG concentrations of 115% of saturation at the tailrace monitor when the concentration in the forebay was about 105% of saturation (Figure 116).

At Little Goose Dam, the period of spill was longer and larger volumes of water were spilled than at the other dams because two of the six turbines were not in operation during the spring. The spill period extended from early May to mid June, and the peak spills occurred on 17-19 May, as at Lower Granite Dam (Figure 117). Dissolved gas concentrations in the forebay at Little Goose Dam were <110% of saturation until spill began at Lower Granite Dam, and then they increased to the 110-120% range, with peak concentrations of nearly 130% of saturation coinciding with peak spills at Lower Granite Dam (Figure 118). Water with high concentrations of total dissolved gas created by the high spill rates (170-180 kcfs) at Lower Granite Dam moved through Little Goose Reservoir in a block and reached the forebay about 30 hours after the period of spill.

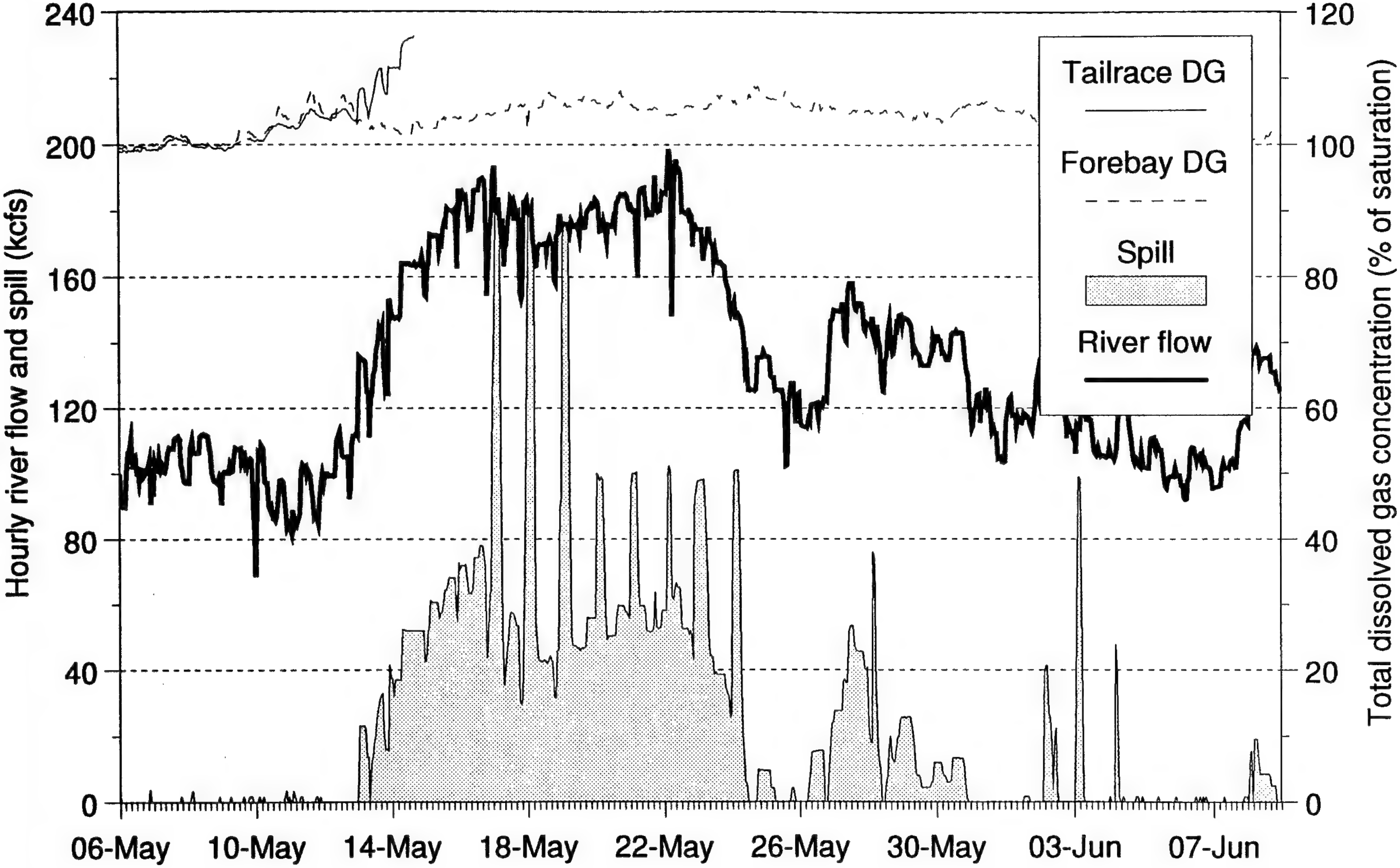


Figure 115. Hourly river flow, spill, and total dissolved gas concentrations in the forebay and at the tailrace site downstream from Lower Granite Dam in 1993.

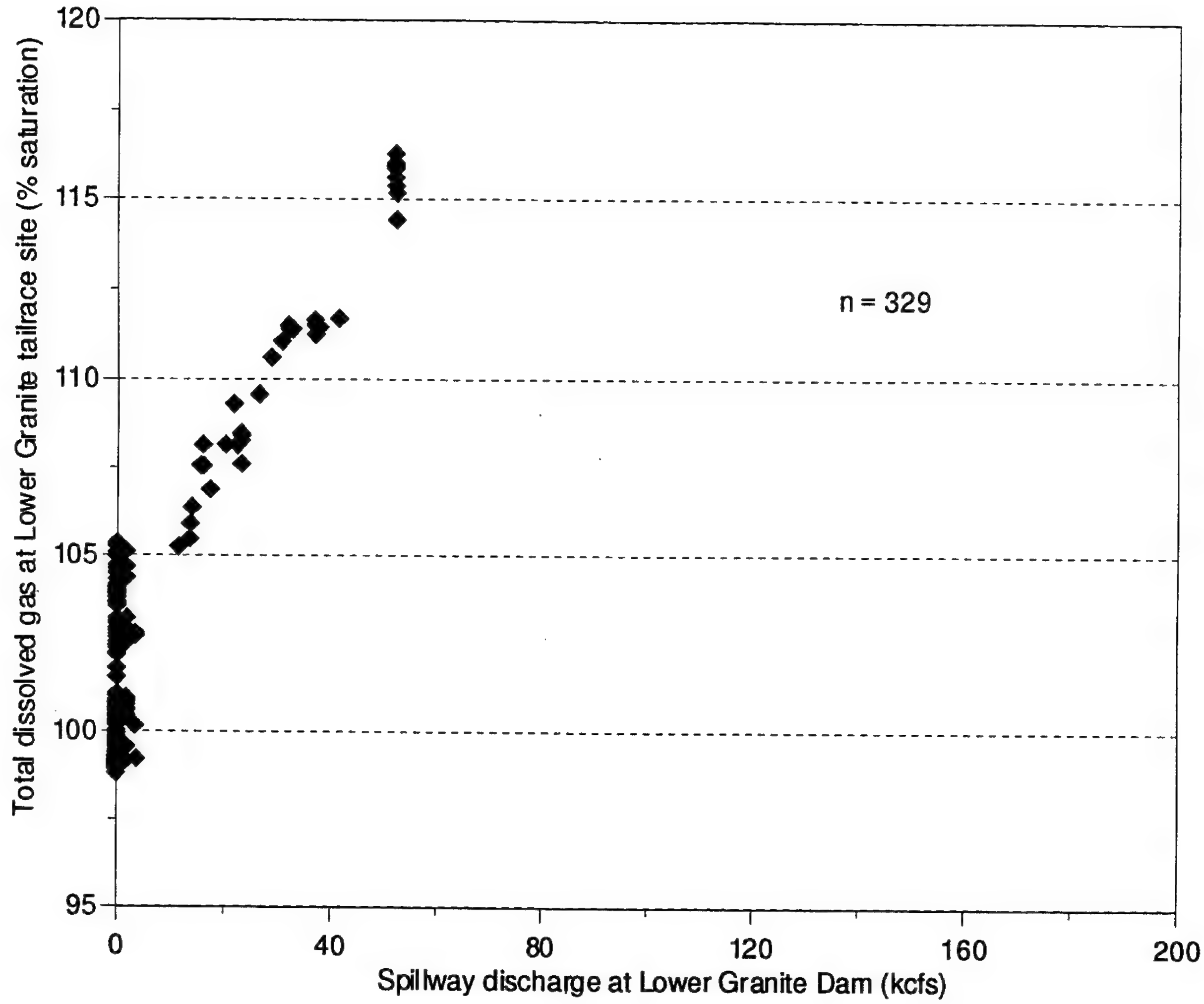


Figure 116. Spill at Lower Granite Dam and total dissolved gas measured at the tailrace receiver site on an hourly basis from 1-14 May 1993.

We do not know the TDG saturation levels in the tailrace of Lower Granite Dam because of the failure of the tailrace monitor. We do know that TDG levels in the Little Goose forebay ranged from about 112% to nearly 130% saturation during the period of spill at Lower Granite Dam (Figure 118), with the highest levels of TDG related to spills of more than 100 kcfs (Figure 119). We could not determine if the TDG saturation level decreased as the water moved through Little Goose Reservoir. Except for the periods when the total river flow (170-180 kcfs) was spilled on 17-19 May, and spills of up to 100 kcfs during the next five nights, hourly spill volumes did not exceed about one-third of theriver flow. Mixing of spilled water with that from the powerhouse would decrease the saturation levels of water moving through Little Goose Reservoir, but we do not know where in the reservoir the mixing is complete.

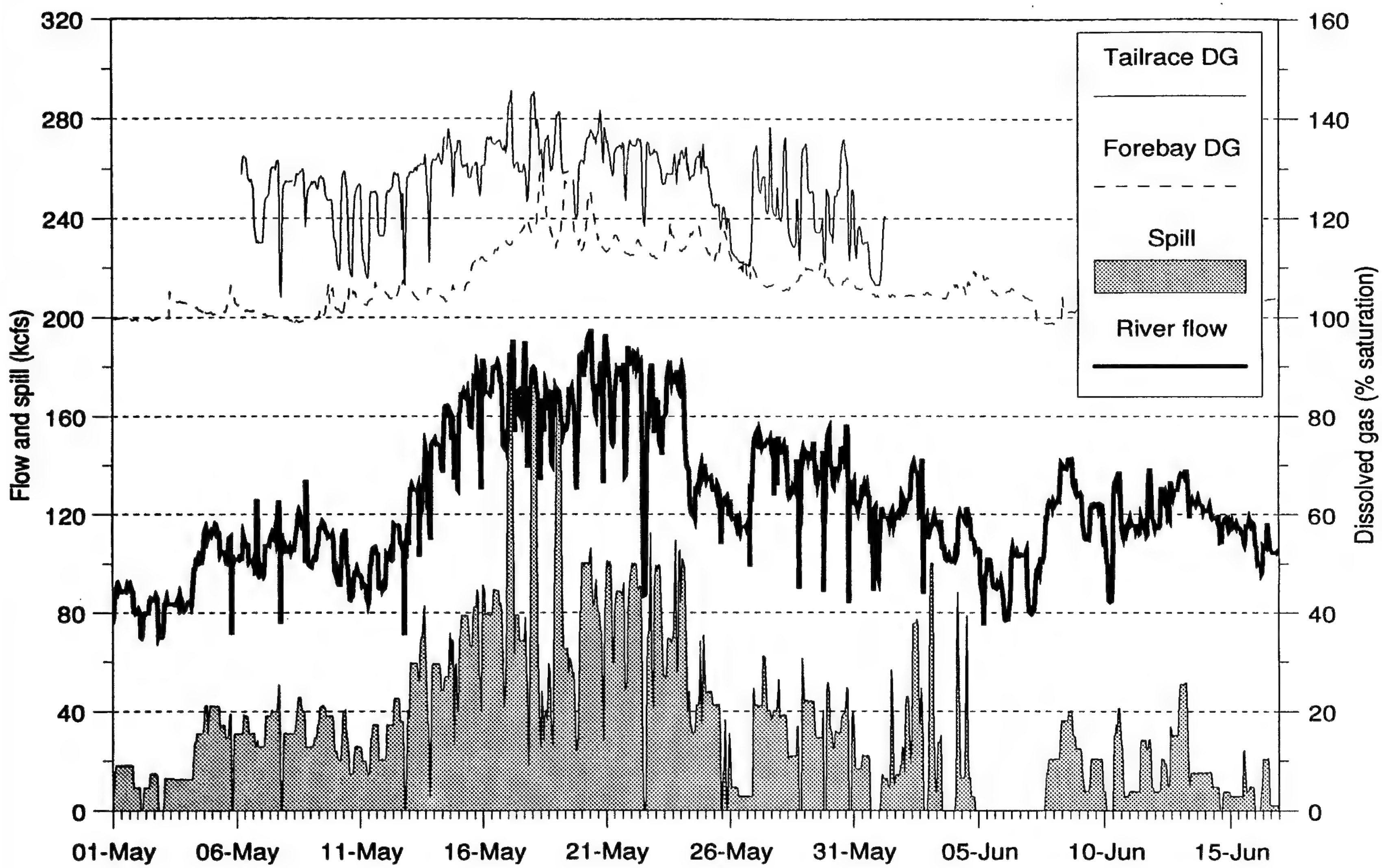


Figure 117. Hourly river flow, spill, and total dissolved gas concentrations in the forebay and at the tailrace site downstream from Little Goose Dam in 1993.

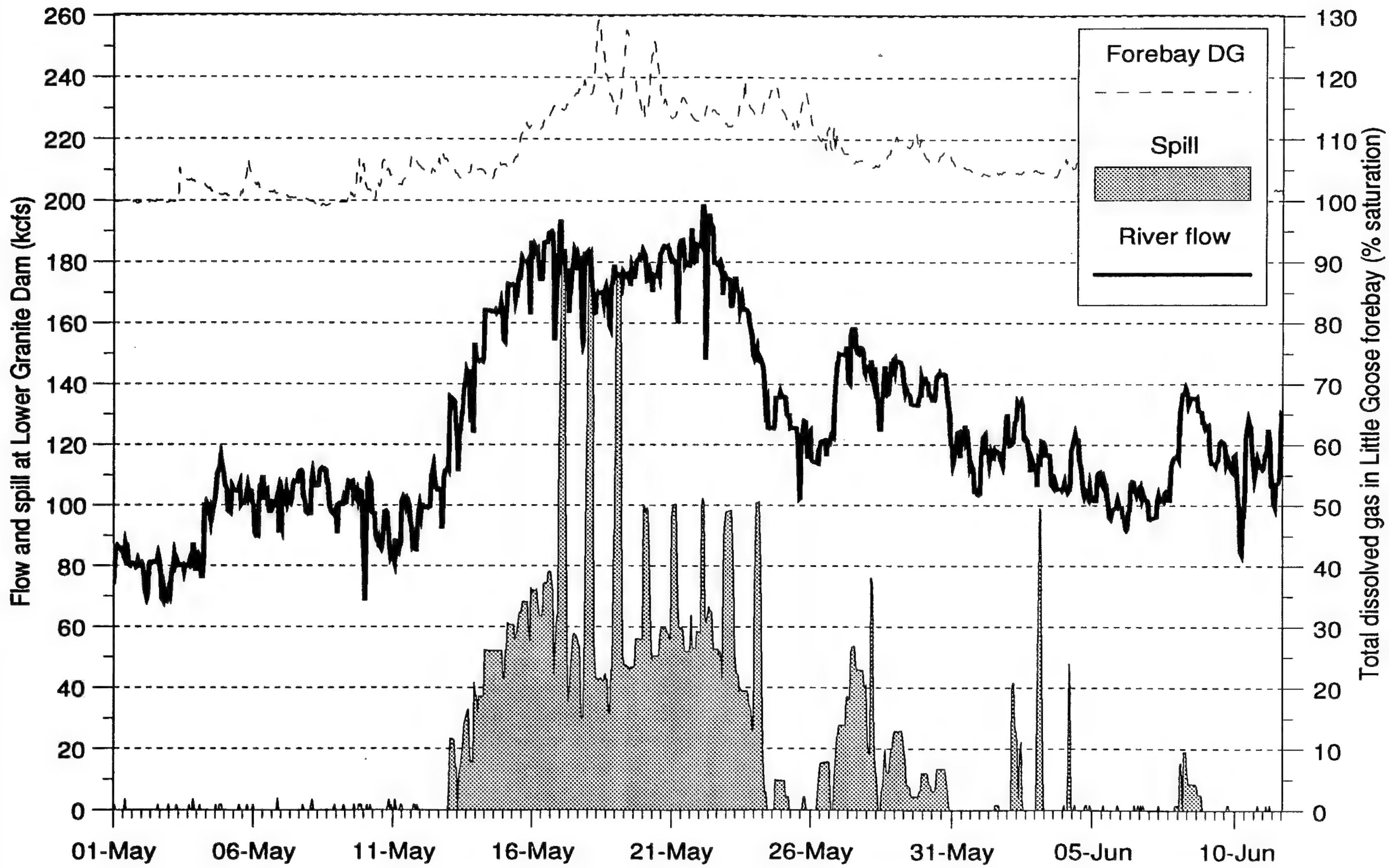


Figure 118. Hourly river flow, spill at Lower Granite Dam and total dissolved gas concentrations in the forebay at Little Goose Dam in 1993.

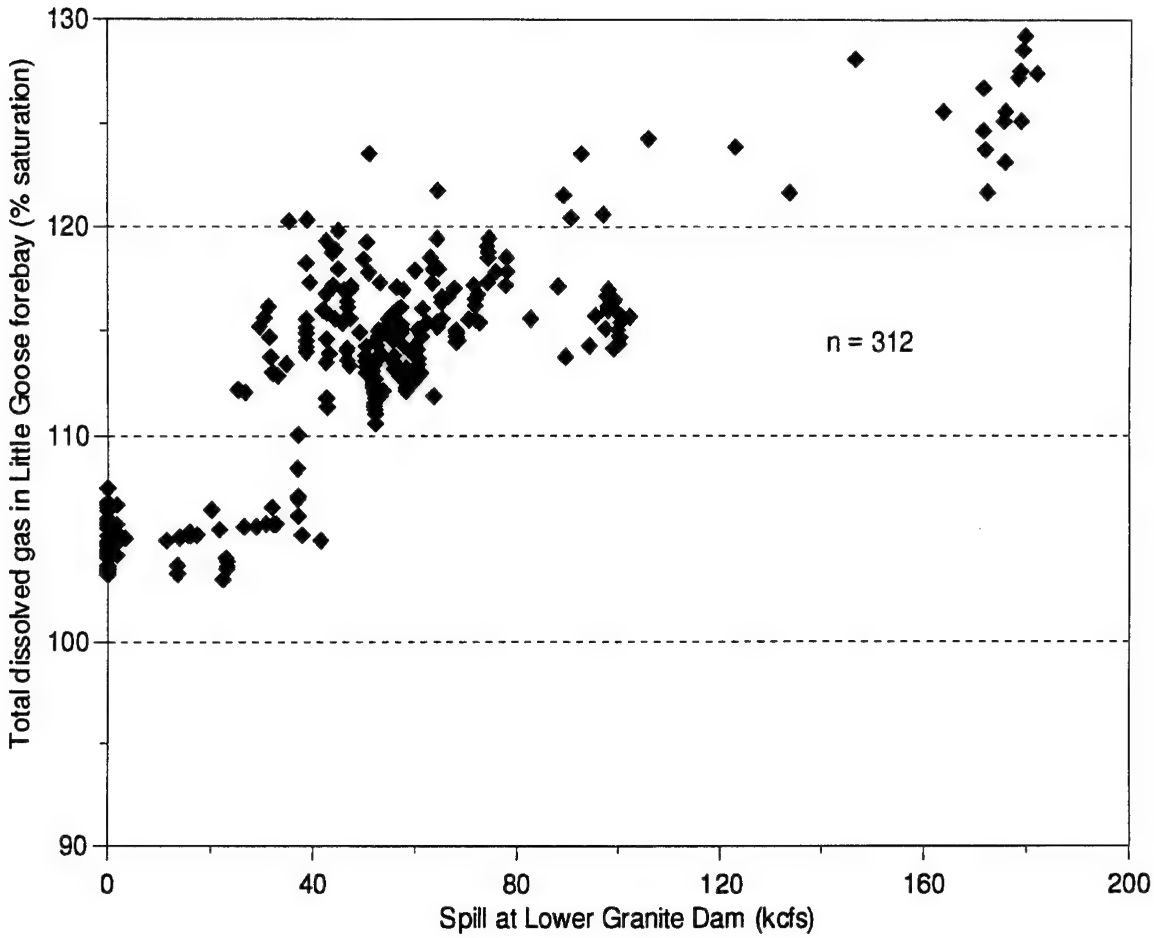


Figure 119. Spill at Lower Granite Dam and total dissolved gas in the forebay of Little Goose Dam on an hourly basis for the period 11-23 May 1993. Total dissolved gas data were shifted forward 30 hours to compensate for the travel time between the two dams.

The relation between volume of spill at Little Goose Dam and TDG concentrations in the tailrace downstream from the dam was variable (Figure 120), mostly because of TDG concentrations created at Lower Granite Dam, but still useful in determining cumulative effects of spilling water at two dams. Concentrations of TDG in the forebay of Little Goose Reservoir were primarily a function of concentrations created at Lower Granite Dam. When there was no spill at Lower Granite Dam the gas concentrations in the Little Goose forebay were <110% (Figure 118), but when there were large volumes of spill at the upper dam, TDG in the Little Goose forebay increased to between 112% and 130% of saturation. Dissolved gas concentrations in the Little Goose tailrace increased with increased amounts of spill and ranged from 120% to 140% of saturation with 40 kcfs of spill. At the highest spill rates in 1993 (about 180 kcfs), gas concentrations ranged from about 135% to 145% of saturation. The spill versus gas concentration relation was asymptotic, probably reflecting an equilibrium between air and water gas concentrations near the 140% of saturation level.

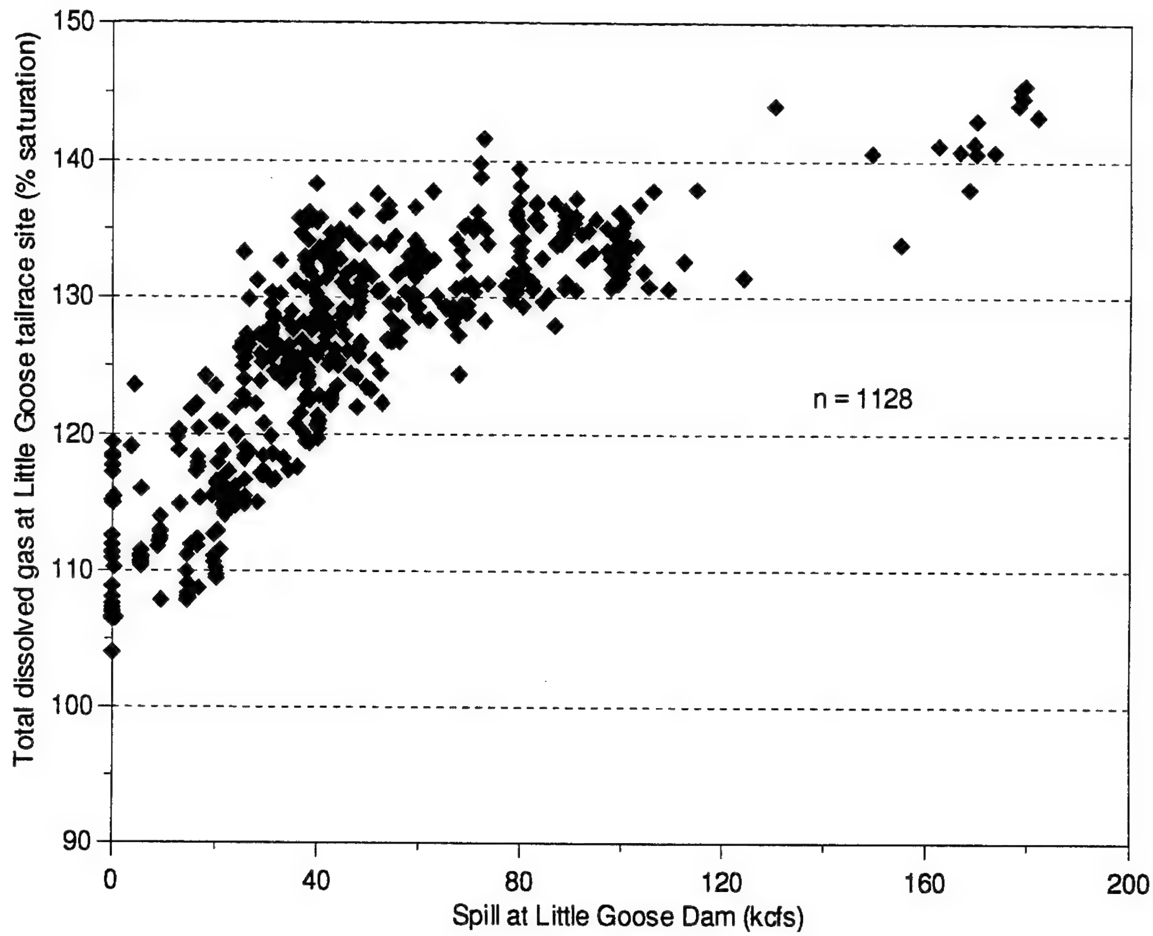


Figure 120. Hourly spill at Little Goose Dam versus total dissolved gas at the tailrace site for the 1 May - 16 June period during 1993.

At Lower Monumental Dam, spill occurred from early May to mid June in 1993 (Figure 121). Total dissolved gas concentrations in the forebay were relatively high in early May (110% to 120% of saturation) because of the 120% to 130% of saturation levels created by the moderate spills (<40 kcfs) at Little Goose Dam. When the peak spills occurred at Little Goose Dam on three nights in mid May, TDG concentrations in the forebay of Lower Monumental Dam peaked at 140% of saturation about 20-22 hours after the peak spills at the upper dam (Figure 121). TDG concentrations at the tailrace site of Lower Monumental Dam ranged from about 115% to 125% when there was <20 kcfs spill at the dam in early May, and the tailrace readings were similar to those in the forebay. When the period of increased spill began in mid May, both forebay and tailrace readings of TDG at Lower Monumental Dam increased to a range of 120% to 130% of saturation.

The relation between volume of spill versus total gas concentration at the Lower Monumental Dam tailrace site was asymptotic with spills of about 40 kcfs creating

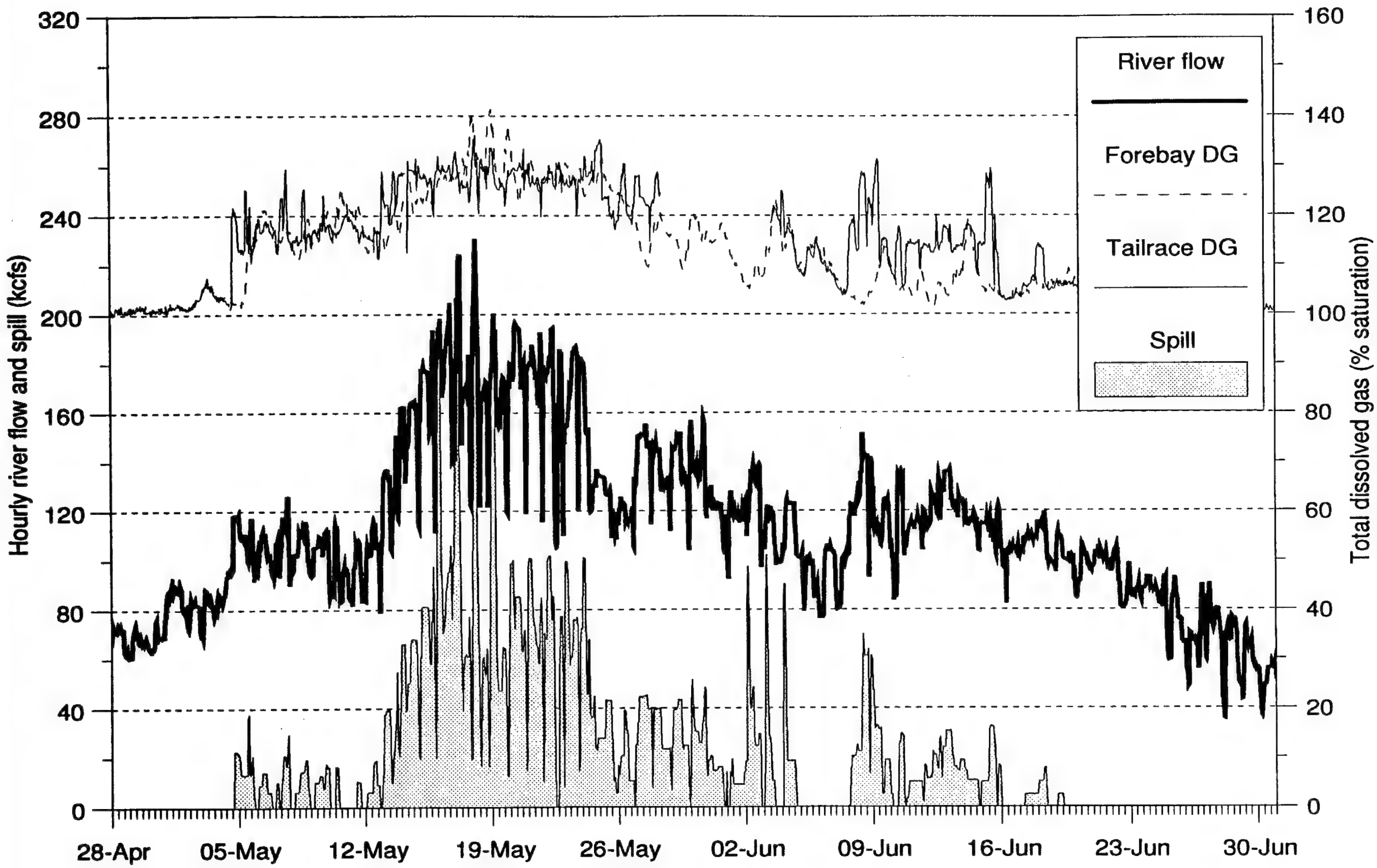


Figure 121. Hourly river flow, spill, and total dissolved gas concentrations in the forebay and at the tailrace site downstream from Lower Monumental Dam in 1993.

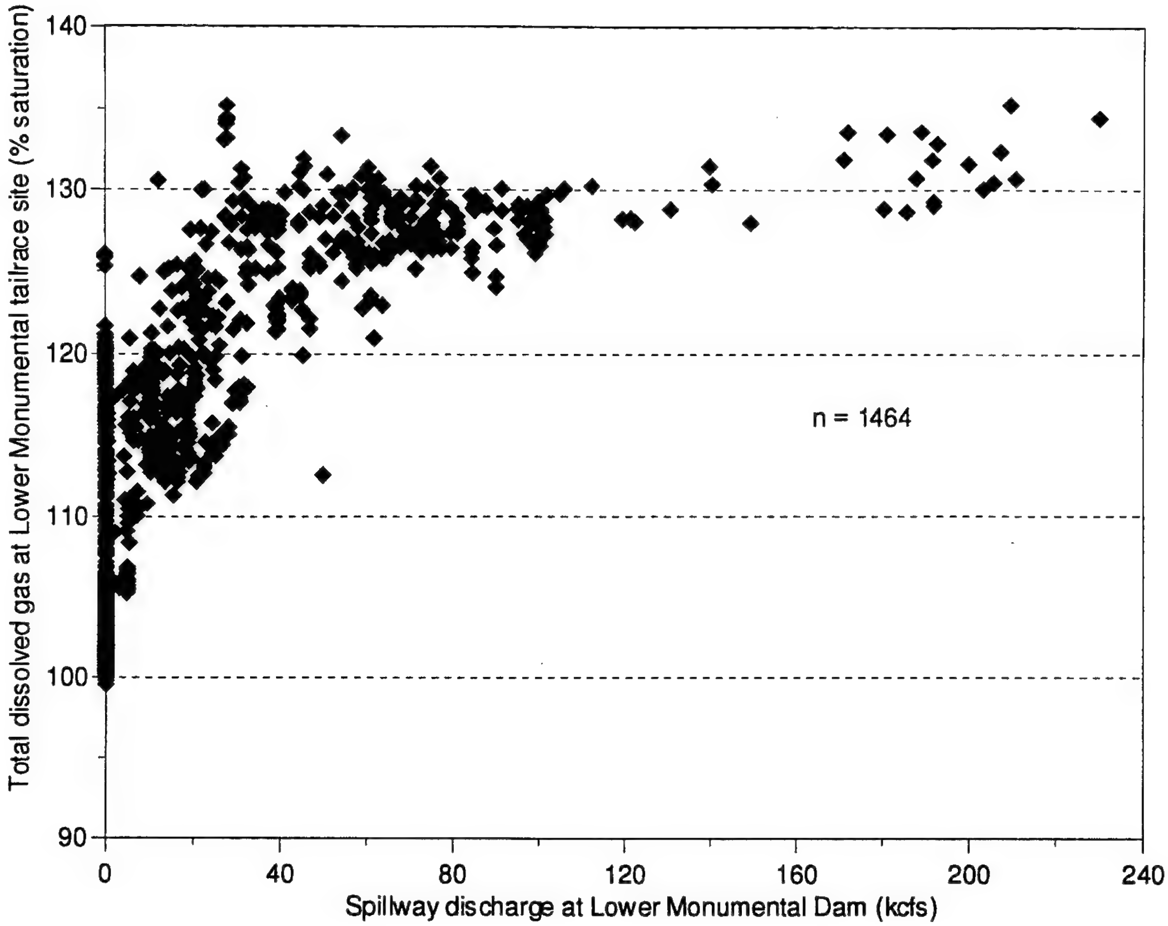


Figure 122. Hourly spillway discharge at Lower Monumental Dam versus total dissolved gas concentration at the tailrace monitoring site from 1 May to 30 June 1993.

dissolved gas concentrations in the tailrace of 120% to 135% of saturation (Figure 122). The persistently high TDG concentrations in the forebay of Lower Monumental Dam, from spills at Little Goose Dam, lead to relatively high concentrations in the tailrace of the dam with low volumes of spill.

Spill to aid downstream migrants passing Ice Harbor Dam occurred from mid April into the summer, but the period of forced spill (river flow exceeded powerhouse capacity or demand) was similar to the upper dams, early May to mid June (Figure 123). Forebay and tailrace concentrations of dissolved gas at Ice Harbor Dam were variable, but generally less than 120% of saturation during the latter half of April, and then increased to above 120% when forced spill started in early May. The primary monitor downstream from Ice Harbor Dam was out of operation during the main period of spill in May, but concentrations were in the 120% to 135% of saturation range immediately before and after the period of large spills. Concentrations in the tailrace remained relatively high (120% to 130% of saturation) through the first half of June.

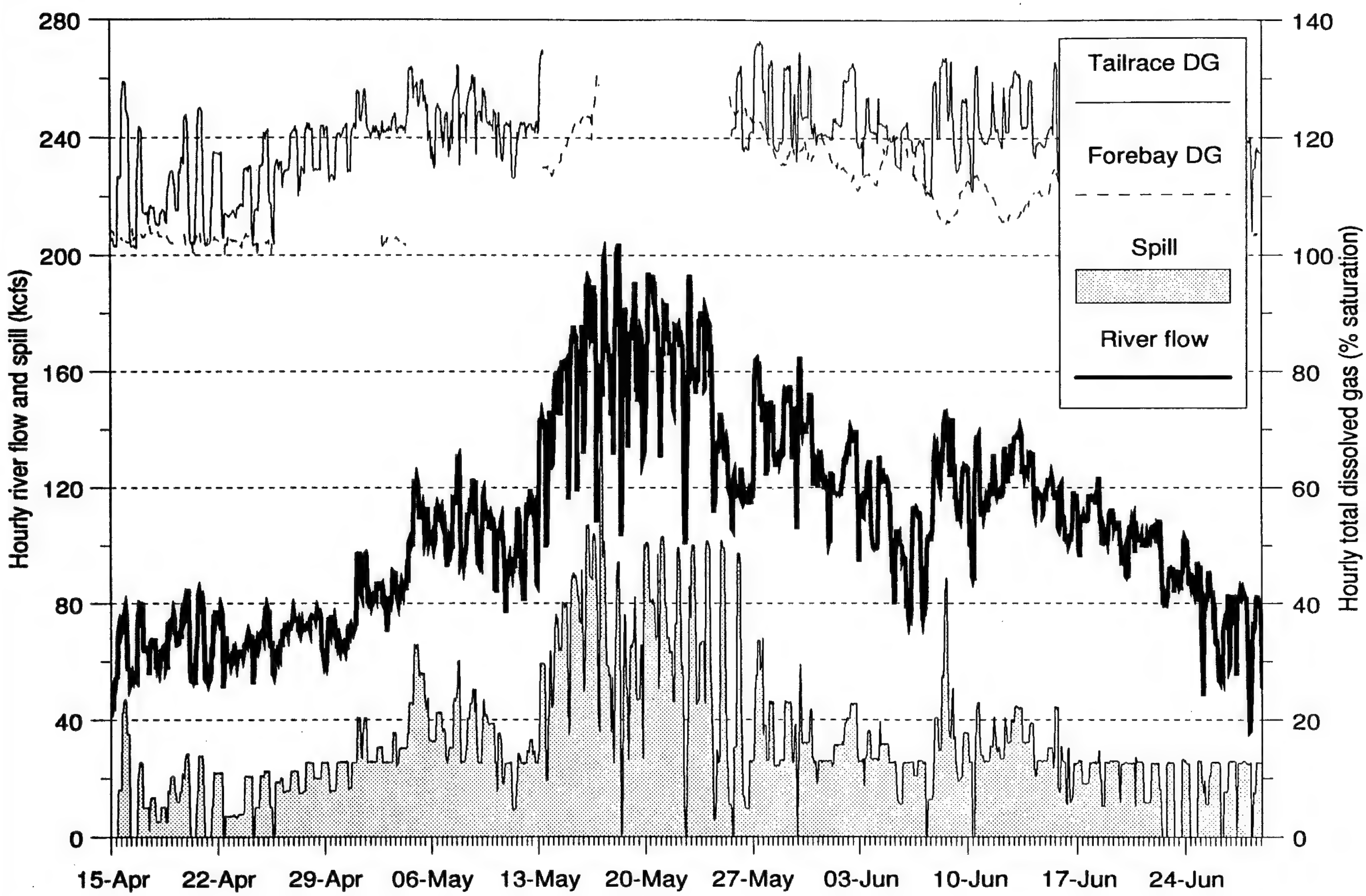


Figure 123. Hourly river flow, spill, and total dissolved gas concentrations in the forebay and at the tailrace site downstream from Ice Harbor Dam in 1993.

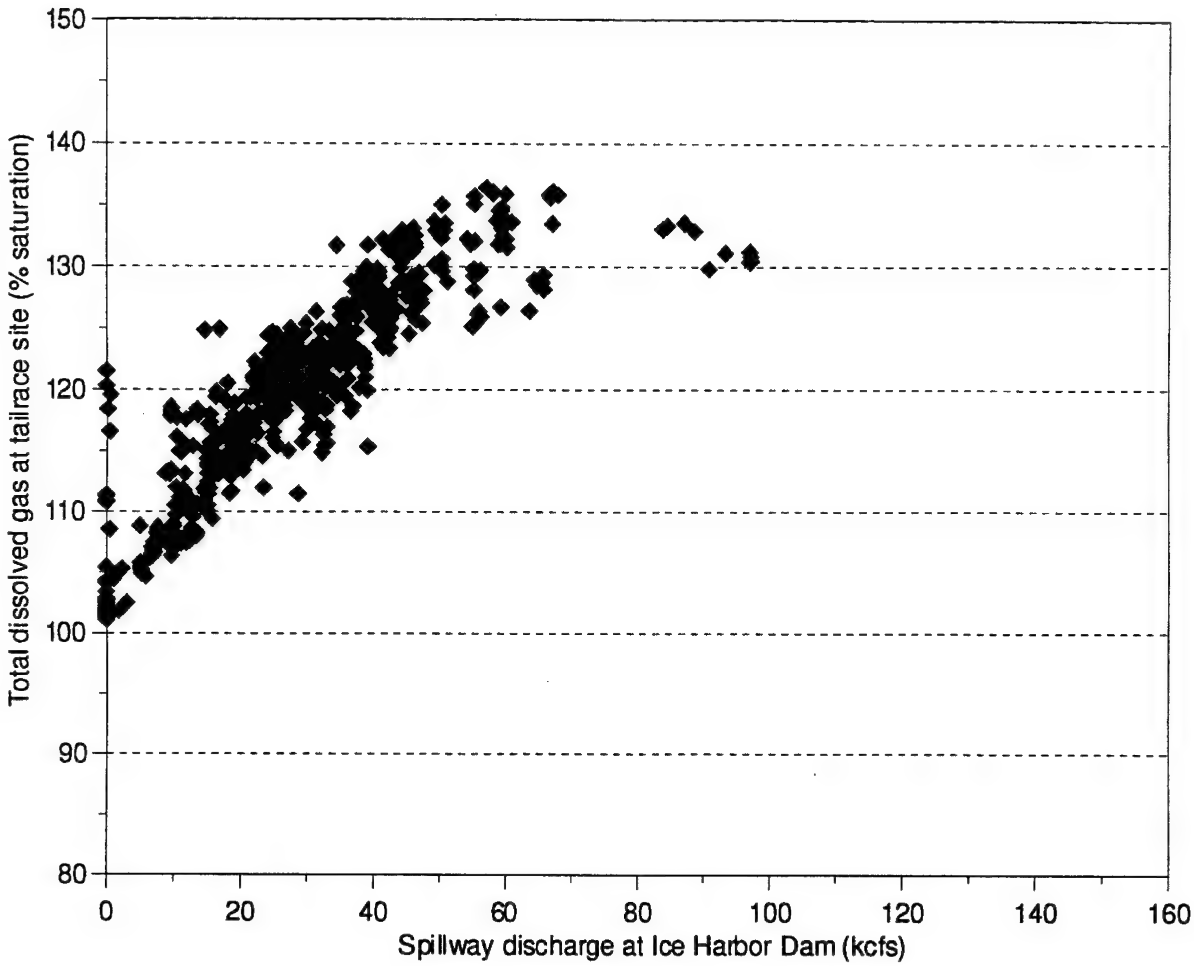


Figure 124. Hourly spillway discharge versus total dissolved gas concentrations at the tailrace site downstream from Ice Harbor Dam for the 15 April - 20 June period in 1993.

Total dissolved gas concentrations in the tailrace downstream from Ice Harbor Dam increased linearly with increased spill volumes up to about 60 kcfs (Figure 124). Although the dissolved gas monitoring record was missing for the high spill period, there was an adequate record to illustrate that dissolved gas concentrations in the tailrace exceeded 120% saturation with relatively small volumes of spill (<40 kcfs) when forebay concentrations exceeded 110% saturation (Figures 123, 124). The higher dissolved gas concentrations in the tailrace at Ice Harbor Dam with relatively low volumes of spill is probably also caused by the lack of "fliplips" on the spillways at that dam.

In summary for the lower Snake River, dissolved gas concentrations start out low in the Lower Granite pool, but the level increases as the water passes downstream over the spillways at the dams so that both the forebays and tailraces of the three lower dams had relatively high gas concentrations (120% to 140% of saturation) during periods of forced spill in 1993. Total dissolved gas concentrations were dependent on the gas

concentrations in the forebay, the volume of spill, the proportion of the total flow that was spilled, and at Ice Harbor Dam, the lack of "fliplips" to reduce supersaturation. When forebay concentrations were relatively low (about 105% saturation), at Lower Granite Dam, gas concentrations in the tailrace increased to about 115% of saturation with up to 50 kcfs of spill (Figure 115, 116). TDG concentrations in the Lower Granite Dam tailrace undoubtably increased further as the amount of spill increased, but we do not know the level because of monitor failure.

At the lower three dams, TDG concentrations in the forebays and tailraces were a function of dissolved gas concentrations generated at upstream dams and spill at each dam. For example, TDG concentrations in the Little Goose forebay were low when there was no spill at Lower Granite Dam, but increased to almost 130% of saturation as river flows and the proportion of the flows that were spilled increased at the upper dam (Figure 125). TDG concentrations at the Little Goose tailrace site were a function of concentrations in the forebay, volume of spills, and flows in the river. When spill volumes were low (relatively low river flows of 62-75 kcfs) and gas concentrations in the forebay were low, then concentrations in the tailrace were also low (Figure 126). When TDG concentrations in the forebay were relatively low (<107% of saturation), but river flows were high enough to cause large amounts of spill (>40 kcfs), concentrations in the tailrace exceeded 130% of saturation. With high concentrations in the forebay and large volumes of spill the tailrace concentrations exceeded 140% of saturation (Figure 126). TDG concentrations in the tailraces of the three lower dams exceeded 115% saturation with smaller volumes of spill (about 20 kcfs, Figures 120, 122, 124) than at Lower Granite Dam because TDG concentrations in the forebays often exceeded 110% saturation. The higher TDG concentrations in the tailraces of the three lower dams, with similar or reduced volumes of spill, is an example of cumulative effects.

In the lower Columbia River, the data on dissolved gas concentrations at the dams was not as complete as in the Snake River, but there was evidence that gas concentrations were relatively high during the 1993 spring runoff. At McNary Dam, dissolved gas concentrations in the forebay were about 110% of saturation in early May, but increased to more than 120% in mid May (Figure 127). In the tailrace, dissolved gas concentrations increased to nearly 140% of saturation when high rates of spill occurred. At John Day Dam, dissolved gas concentrations in the forebay increased to more than 115% of saturation during the main period of spill at the dams in the latter half of May and early June (Figure 128), an indication that salmon migrating up the river at that time were exposed to relatively high dissolved gas levels in the lower Columbia River as well as in the Snake River. TDG data for the tailrace was not collected at John Day Dam in 1993.

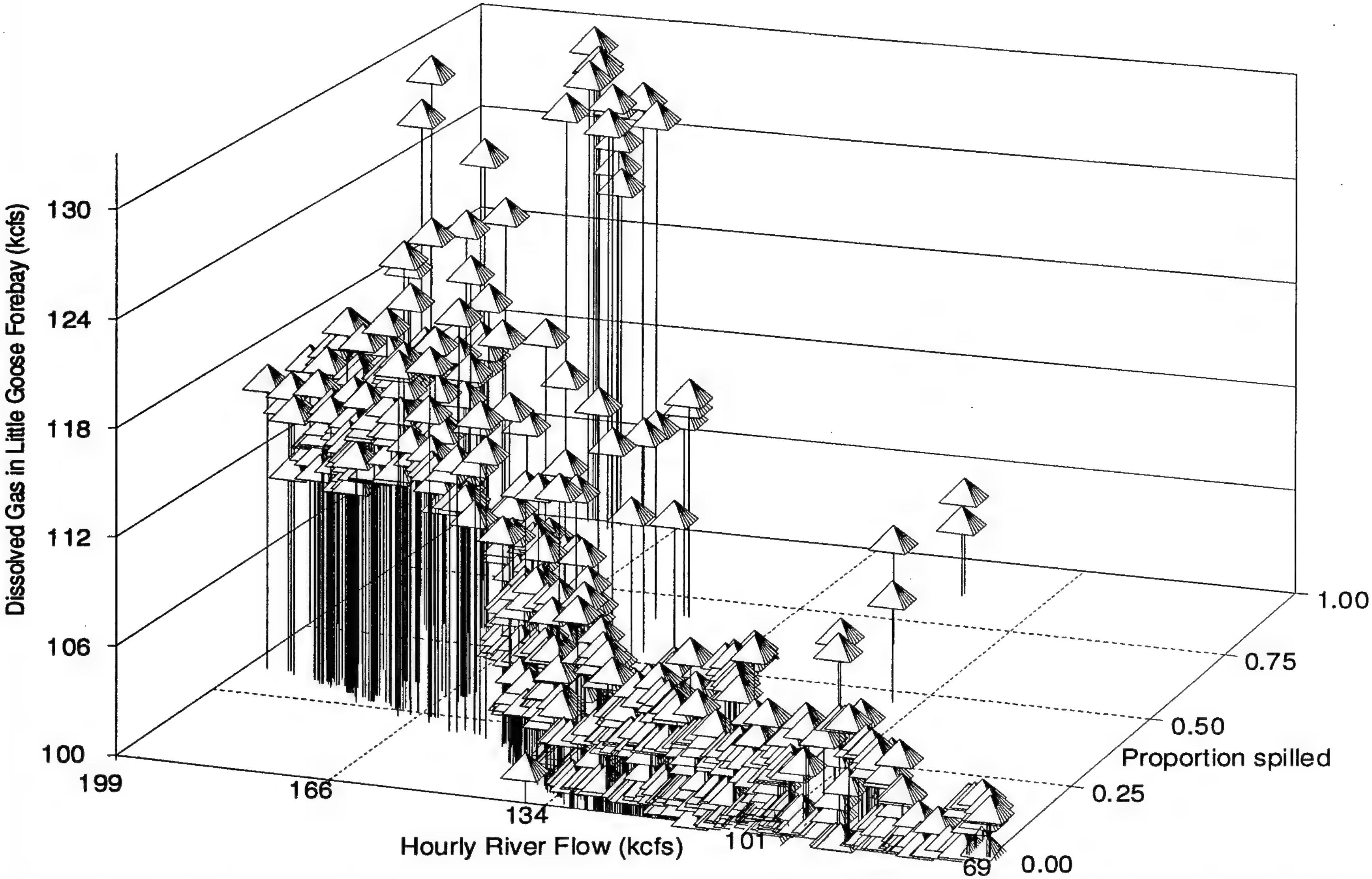


Figure 125. Total dissolved gas concentrations (% saturation) in the forebay of Little Goose Dam related to the hourly flow in the river and the proportion of the flow that was spilled at Lower Granite Dam 30 hours earlier during the 30 April -12 June period in 1993.

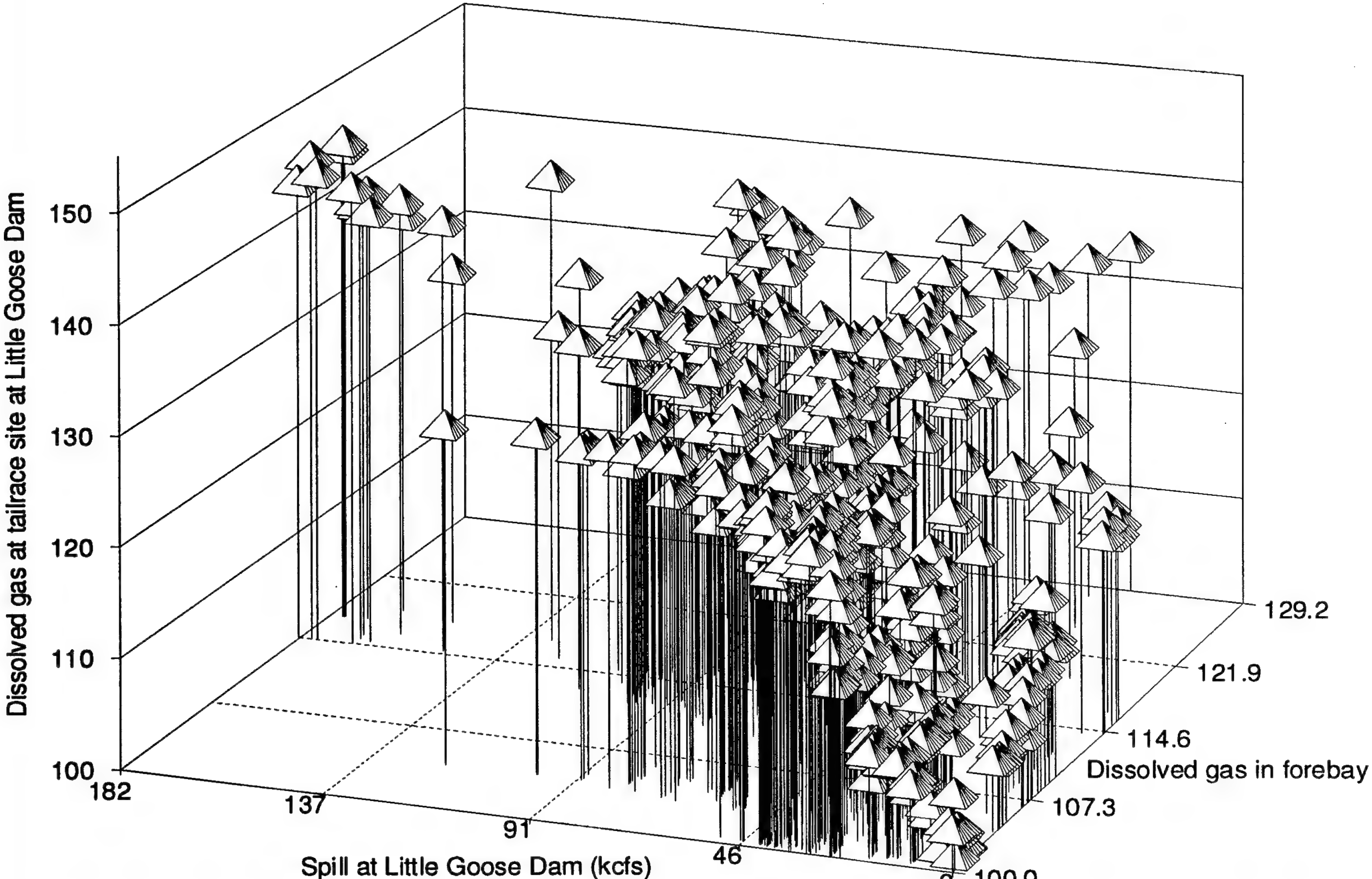


Figure 126. Total dissolved gas concentration (% saturation) at the tailrace site downstream from Little Goose Dam versus hourly spill and dissolved gas concentration in the forebay of the dam during the 29 April - 2 June period in 1993.

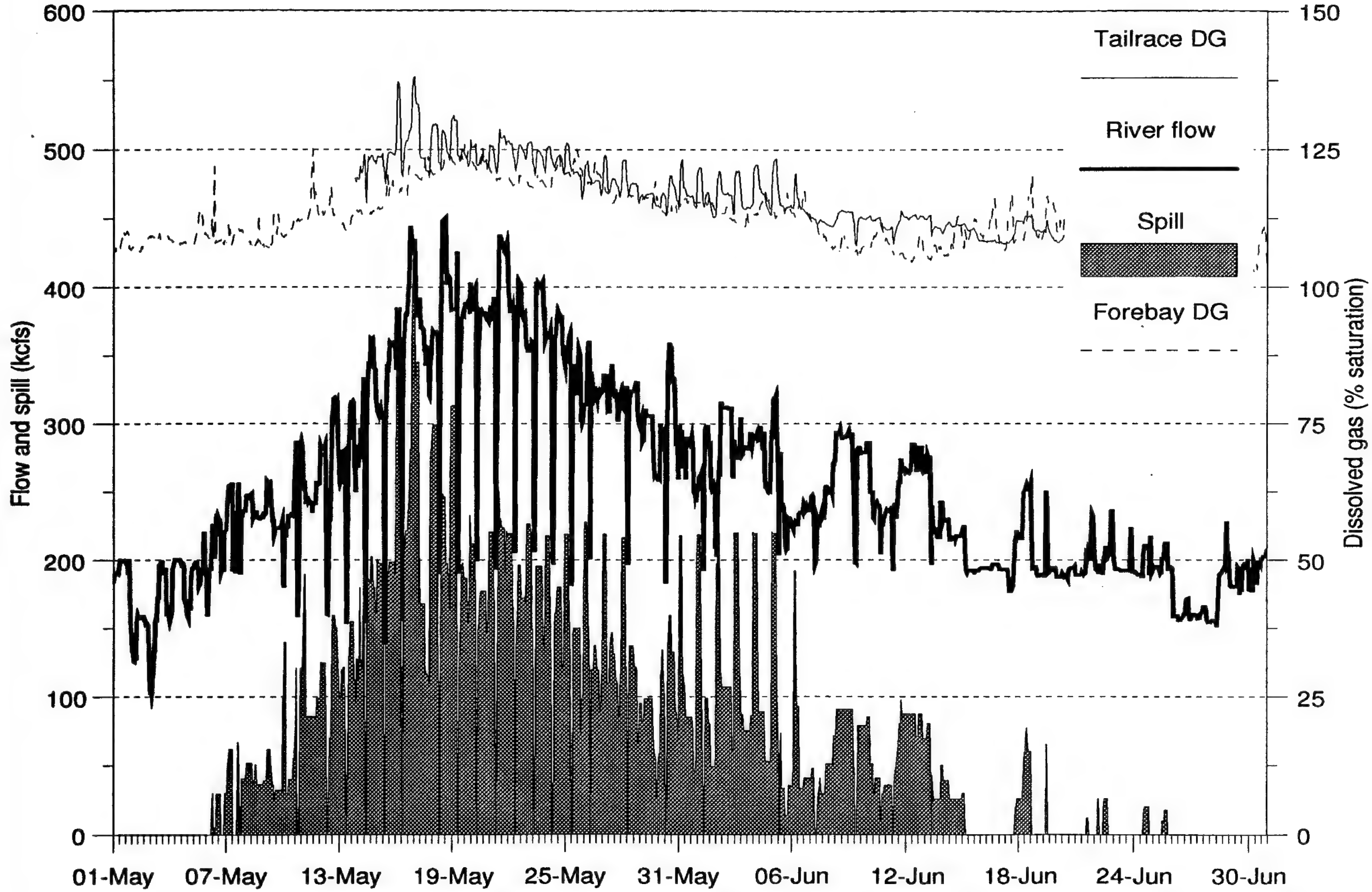


Figure 127. Hourly river flow, spill, and total dissolved gas concentrations in the forebay and in the tailrace downstream from McNary Dam in 1993.

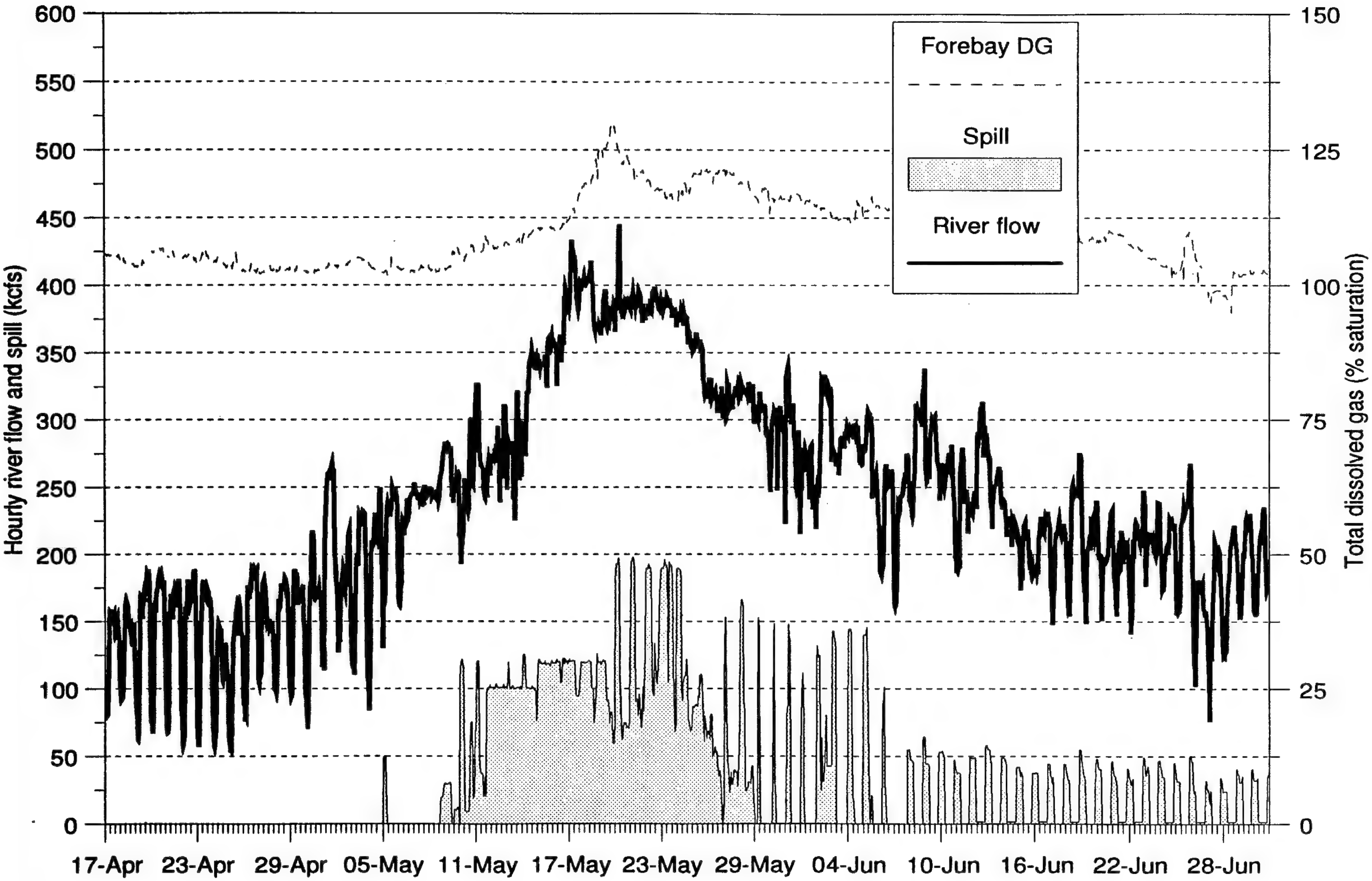


Figure 128. Hourly river flow, spill, and total dissolved gas concentrations in the forebay at John Day Dam in 1993.

Incidence of Head Scrapes and Migration Timing of Chinook Salmon

During the spring and summer of 1993, chinook salmon with transmitters migrated from John Day Dam through the lower Snake River and were then recaptured at the Lower Granite Dam trap where they were examined for transmitters, tags, marks, and injuries. None of the fish had scrapes on the head that might be classed as "head burns" when captured and outfitted with transmitters at John Day Dam. At Lower Granite Dam, 72 of 323 salmon examined (22.3%) that had transmitters or VI tags had some degree of scrape on the head.

Salmon reported to have scrapes on the head when they passed over Lower Granite Dam were tagged at John Day Dam as early as 22 April and as late as 28 June (Figure 129). Researchers began tagging fish at John Day Dam on 19 April and continued through 29 July. Fish that crossed over John Day Dam in July were not subjected to the high flows, spill, and dissolved gas concentrations (Figure 128).

The timing of recapture of the chinook salmon with scrapes on the head at Lower Granite Dam was related to the period of high flows and spill. The first salmon recorded with head scrapes was on 17 May (Figure 130) during the peak period of spill. All the rest of the fish with head scrapes crossed over the dam after 23 May, with most passing by 16 June (Figure 130), about two weeks after the main period of spill at the Snake River dams.

Of the 72 chinook salmon with transmitters recaptured at the Lower Granite adult trap with head scrapes, data were complete enough on 66 of the fish to categorize them and estimate their ultimate fate. The other six fish were recorded as having transmitters at Lower Granite Dam, but the frequencies and codes were not recorded, nor were the VI-tag numbers, so we could not identify them later as fish with head scrapes.

Of the 66 fish with adequate information, 5 were classed as hatchery fish at time of tagging because they had an adipose fin clip. The remainder were naturally produced fish or hatchery fish without a fin clip. Three of the five fish with adipose fin clips were recorded in the South Fork of the Salmon River, two downstream from the weir, and one released to spawn naturally upstream from the weir. The other two were last recorded in the Snake River and lower Columbia River and classed as unknown fates, but probably as fish that died before spawning.

Thirty-seven of the 66 fish (56.1%), were last recorded in spawning areas and were classed as having spawned. Four of the fish (6.1%) returned to hatcheries; these were fish without fin clips. Thirteen of the fish (19.7%) were last recorded in areas that were not traditional spawning areas during or after the spawning season and were classed as fish the died before spawning. The remaining 12 fish (18.2%), were classed as fate unknown because there were no records after recapture at Lower Granite Dam or the last records were from areas that were not spawning areas and were before spawning

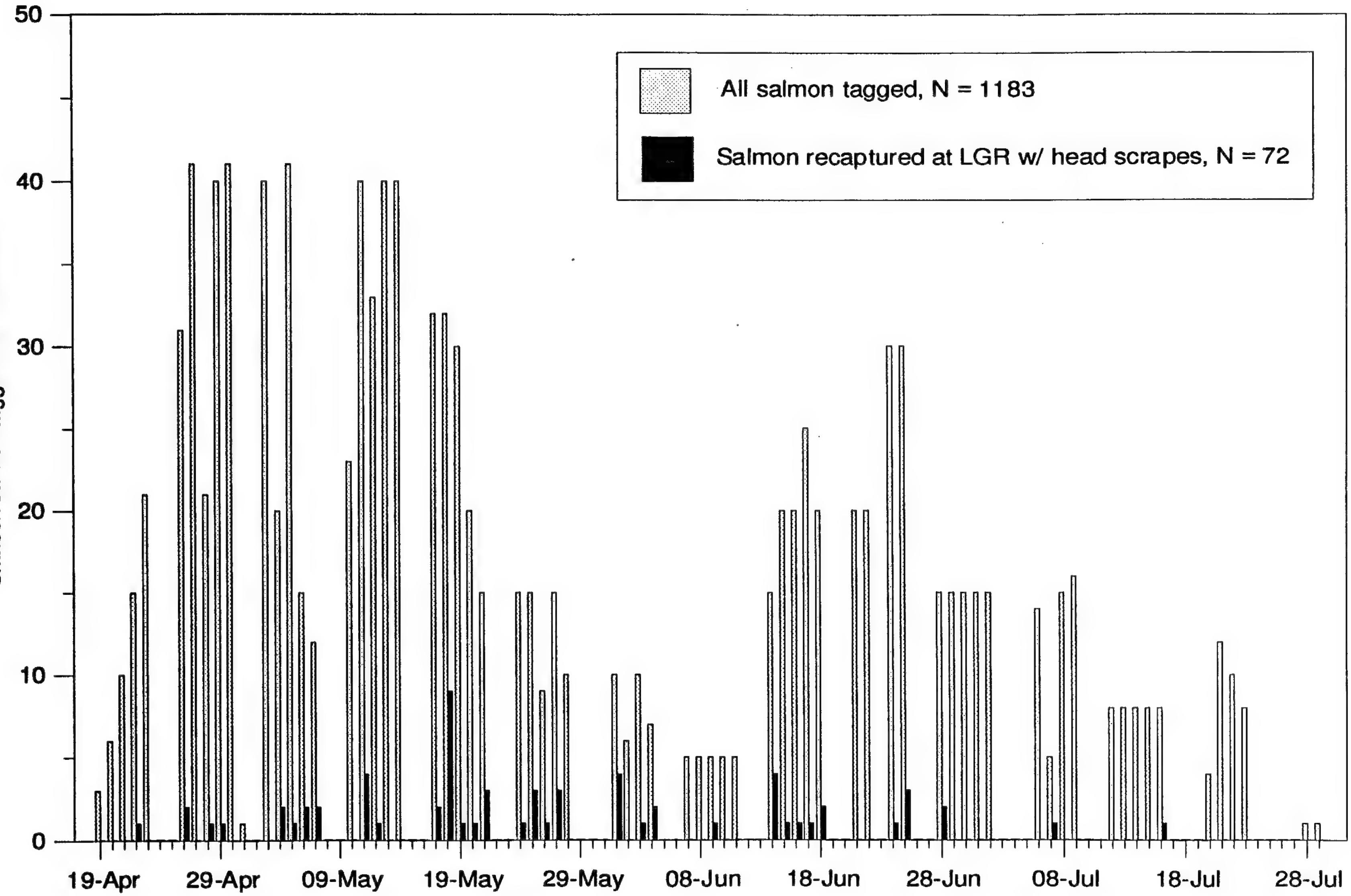


Figure 129. Number of chinook salmon outfitted with transmitters and tagged with VI tags at John Day Dam, and number of salmon recaptured at Lower Granite adult trap with scrapes on the head, by date of tagging in 1993.

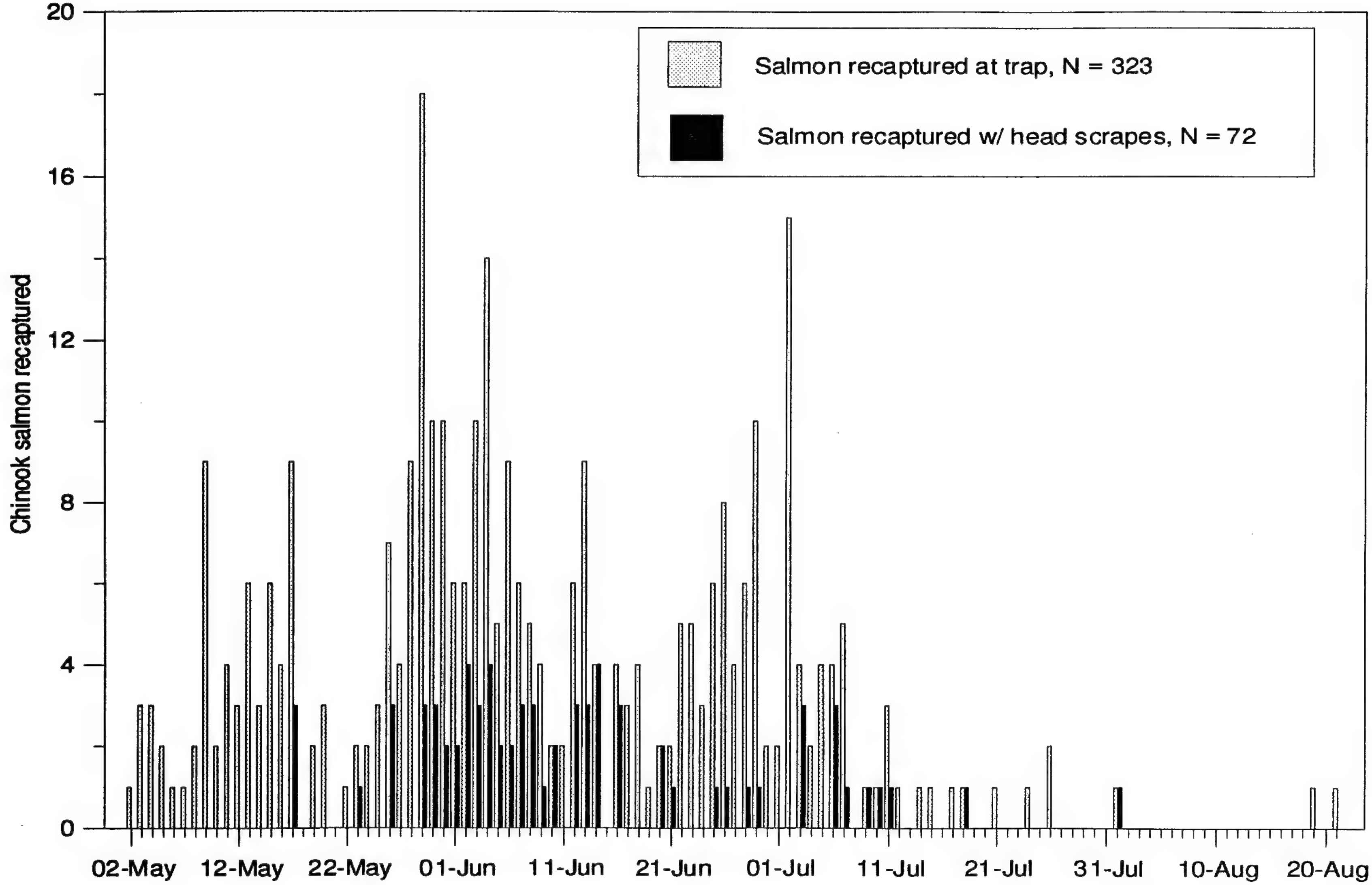


Figure 130. Number of chinook salmon outfitted with transmitters and tagged with VI tags that were recaptured at the Lower Granite adult trap, and number recaptured with scrapes on the head, by date of recapture in 1993.

season. If most of this latter group died before spawning, then about 38% of the 66 fish with head scrapes probably died before spawning. Our estimates of the minimum prespawning loss for all salmon with transmitters that crossed over Ice Harbor Dam in 1991 to 1993 were 46%, 37%, and 22%, respectively, thus the loss of fish with head scrapes after recapture at Lower Granite Dam may be higher than the loss of fish without the scrapes.

Timing of the spill and passage of chinook salmon with head scrapes over Lower Granite Dam is circumstantial evidence that the head scrapes were related to high volumes of spill and might have been symptoms of gas bubble disease caused by the relatively high dissolved gas concentrations in the Snake River during the latter half of May and early June. The timing, coupled with the high incidence of head scrapes observed in 1993 versus low incidences in the prior six years, when no spill occurred, increases the likelihood that the head scapes were related to the high levels of spill and/or the TDG concentrations. It was not possible to determine if the head scrapes were injuries that occurred from fish colliding with structures at the dams or in the river, or if they were the result of gas bubble disease.

Discussion

Conditions for upstream migration of adult spring and summer chinook salmon in the lower Snake River were different in 1993, from the two previous years because there was a significant period of spill at each of the dams during May and June (Figures 51-54). The period of daytime spill varied from dam to dam depending on the number of turbines that could be operated and the power demand. The duration of daytime spill ranged from nearly two weeks at Lower Granite Dam to about eight weeks at Ice Harbor Dam. Peak flows and spill occurred during the latter half of May at all the dams, and coincided with reduced numbers of fish passing each of the dams (Figures 65, 72, 79, 86).

Migration rates of salmon with transmitters observed for the entire migration period in 1991, 1992, and 1993 were near the high end of the range observed in past studies (Bjornn and Peery 1992), despite the spill in 1993, and probably represent the rates that can be expected under conditions that are favorable for upstream migrants. The mean times for chinook salmon to pass Lower Granite Dam were 3.1 d in 1991, 2.3 d in 1992, and 1.8 d in 1993. Turner et al. (1983) reported that chinook salmon took nearly 8 d on average to pass Lower Granite Dam when spill exceeded 25 kcfs versus only 2 d when there was less spill in 1981. The mean time to pass from the tailrace receiver at Lower Granite Dam and enter the fishway in 1993 ranged from 2.3 to 4.0 hours with low (<40 kcfs) and medium (40-80 kcfs) spill volumes, versus 11.5 hours when there was no spill. The median times to enter the fishway, a better statistic for comparison, ranged from 1.9 to 3.3 hours for periods of low, medium, and no spill. No fish with transmitters entered the fishway at Lower Granite Dam when spill volumes were high (>80 kcfs).

In 1993, the median times for spring and summer chinook salmon to pass the four lower Snake River dams ranged from 0.6 to 1.2 d, with the longest time at Lower Granite Dam. The time to pass Lower Granite Dam in 1993 was similar to that observed in 1992 (1.3 d), but the time to pass Ice Harbor Dam was reduced from 1.2 d in 1992 to 0.8 d in 1993. The reduction in passage time was probably the result of moving the trapping and tagging of fish to John Day Dam in 1993, which eliminated the need to trap fish at Ice Harbor Dam. Operation of the trap at Ice Harbor Dam, as in 1992, appears to cause about 0.4 d delay for chinook salmon passing the dam. The median passage time at Ice Harbor Dam was 5.4 d in 1991, but was reduced to 1.2 d in 1992 by removing the trap box from the water when trapping was finished each day, thereby allowing the fish to migrate past the trapping site in the ladder through the entire water column instead of under the trap.

Migration rates of chinook salmon with transmitters through the Snake River reservoirs in 1993 ranged from 20 to 59 km/d based on mean times to pass, and 31 to 65 km/d based on median times to pass. The rates in 1993 were similar to those observed in 1991 and 1992 (about 25 to 63 km/d; Bjornn et al. 1992; 1994). The slowest rates

were observed for salmon migrating through Lower Granite Reservoir to the lower end of the Clearwater River or the Snake River near Asotin. In free-flowing rivers upstream from the dams, migration rates of salmon with transmitters ranged from 12 to 20 km/d (based on mean days to pass) and 10 to 30 km/d (based on median days) in 1993, rates that were similar to those observed in 1991 and 1992 (12-38 km/d), and similar to those observed in prior years (Turner et al. 1983, 1984; Oregon Fish Commission 1960).

Success of passage of spring and summer chinook salmon with transmitters from the tailrace at Ice Harbor Dam to the receivers upstream from the Lower Granite Reservoir was 86.1% in 1993 versus 79% in 1992. Passage from the top of Ice Harbor to the top of Lower Granite dams was 90% in 1993, versus 87% in 1991 and 85% in 1992, rates that are similar to that observed from an analysis of counts of all adults at the two dams from 1975 to 1989 (Bjornn 1990), in 1992 (83% passage), and in 1993 (91.8%). Survival from the Ice Harbor Dam tailrace to the spawning grounds or hatcheries was estimated to be no more than 77% in 1993, versus 63% in 1992 and 54% in 1991. These estimates are maximum survivals because fish that died before spawning in some streams could not be estimated. In a separate effort, Bjornn (1990) estimated that 45 to 55% of the wild chinook salmon passing Ice Harbor Dam survived to spawn during the 1962 to 1988 period.

The capture, tagging and release of salmon at John Day Dam in 1993 provided an opportunity to determine if capturing the fish at Ice Harbor Dam and releasing them 16 km downstream from the dam after tagging caused some of the fish to give up trying to continue their migration up the Snake River. The fish that approached Ice Harbor Dam in 1993 were naive fish that had not been to the dam before, whereas fish with transmitters that approached the dam in 1991 and 1992 had already passed the dam once. In 1993, 22 of 362 (6.1%) salmon that entered the tailrace at Ice Harbor Dam did not cross over the dam, but of the 340 that did pass the dam, 339 proceeded upstream and were detected in the tailrace of Lower Monumental Dam. In 1992, 22 of 519 (4.2%) salmon that entered the tailrace at Ice Harbor Dam failed to cross the dam. Based on those two years of data, capturing the salmon at Ice Harbor Dam and then releasing them downstream after tagging may not have caused fish to abort their migration up the Snake River.

Based on the time of passage at Ice Harbor Dam, we were able to use the fish with transmitters to increase the information available on the distribution of spring versus summer chinook salmon in the Snake River basin. The distinction between spring and summer chinook salmon begins with their time of entry into the Columbia River and passage over Bonneville Dam. The separation in timing usually continues as the fish migrate up the river. In 1991, there was a nadir in the counts of chinook salmon at Ice Harbor Dam in late May that coincided with a pulse of turbid water that passed through the system. In 1992, there was no pulse of turbid water, but there was a nadir in the counts about the 20th to 25th of May. In 1993, there was a nadir in the number of

salmon counted at the dams during the third week May that coincided with the peak flows and highest turbidities. The counts of salmon increased after the flows decreased, but then declined again in early June before increasing again. We believe the high, turbid flows caused the nadir in May and that the one in early June was the separation between spring and summer chinook salmon that often occurs at that time. We suspect that the fish we tagged and released in April, May and the first few days of June were mostly spring chinook salmon and those tagged and released after early June were mostly summer chinook salmon. But, keep in mind when looking at the distribution data that early migrating summer chinook salmon may have reached Ice Harbor Dam by late May in 1993, and that delayed spring chinook salmon may not have made it to Ice Harbor Dam until mid June. The distribution of salmon in 1991, 1992, and 1993 varied by drainage and hatchery with some having entirely spring or summer chinook salmon and some areas a mixture of both. As additional years of data are added, we will have a clearer understanding of the fish that make up the stocks in each spawning area and hatchery.

In 1993, of the 1,171 salmon released at John Day Dam, 63.7% were captured and released before 5 June, the usual cutoff date between spring and summer chinook salmon at John Day Dam, and the remainder were released later in June and July. Of the 291 salmon known to have passed over Lower Granite Dam in 1993, 69.8% would be classed as spring chinook salmon based on date of tagging, and the rest summer chinook salmon. The distribution of spring and summer chinook salmon with transmitters into the major Snake River tributaries for the years 1991, 1992, and 1993 varied , with 0%, 4%, and 5%, respectively, into the Tucannon River, 25%, 15%, and 21% into the Clearwater, 0%, 2%, and 4% into the Snake River proper upstream from Lewiston, 9%, 10%, and 11% into the Grande Ronde, 4%, 5%, and 8% into the Imnaha, and 62%, 63%, and 51% into the Salmon river drainages. The distribution probably reflects the amount of natural and hatchery production in each drainage.

Detailed information on time to enter the fishways, fishway entrances used, fallout from the fishways, and time to pass a dam by spring and summer chinook salmon with transmitters was collected in 1993 at all four Snake River dams by using the DSP/SRX receivers. The median times for salmon to move from the tailraces up to the dams where they were detected as they approached the entrances to the fishways were less than 2 hours at all four dams. The median times to first entry into the fishways were less than 4.5 hours, and the times to pass over the dams were less than a day (0.70 to 0.85 d).

The time salmon with transmitters used to pass from the tailraces of the dam to their first entry into the fishways did not differ much when grouped by spill conditions. The median time to first entry ranged from 1.4 to 3.3 hours when there was no spill, low spill (<40 kcfs), or medium spill (40-80 kcfs). No fish passed from the tailraces into the fishways when spills exceeded 80 kcfs.

In 1993, the entrances chinook salmon first approached at the dams varied by dam, with the north shore entrance approached by the largest number of fish at Ice Harbor, orifice gate 1 at Lower Monumental, south shore entrance at Little Goose, and north powerhouse 2 entrance at Lower Granite dams. Entrances used by the most fish for their first entry into the fishways were the north shore at Ice Harbor and Little Goose, south shore at Lower Monumental, and north powerhouse 2 at Lower Granite dams. The entrances used for first exits from the fishways were north powerhouse at Ice Harbor and Lower Granite, and south shore entrances at Lower Monumental and Little Goose dams. Entrances with the highest net entries were the north shore at Ice Harbor and Little Goose, south shore at Lower Monumental, and north powerhouse 2 at Lower Granite dams. In summary, the entrances at either end of the dams were usually the ones used by most of the fish.

The level of spill and the spill pattern caused some shifts in the entrance used most frequently for first entry into the fishways. At Ice Harbor Dam, the south shore entrance was used by the largest number of fish with no daytime spill, but shifted to the north shore entrance with low levels of spill, and to the north powerhouse entrance with medium spill and the alternate spill pattern. At Lower Monumental Dam, the entrance to the south shore ladder was used by the largest number of salmon with all spill volumes and patterns. At Little Goose Dam, the south shore and orifice gate 1 openings were used by the largest number of fish with no spill or low spill with the regular patterns, but fish use shifted to the north shore entrance with low spill and the alternate pattern or medium spill. At Lower Granite Dam, the north powerhouse 2 entrance was used by the most fish with no spill or low spill with the alternate pattern, but north shore entrance was used by the largest number of fish when low spill and the regular pattern or medium spill occurred.

The fishway fence installed in the Little Goose Dam fishway adjacent to north powerhouse entrances 1 and 2 appeared to guide fish out those two openings if the fish are moving downstream in the powerhouse collection channel. Salmon exiting the fishway at NPE-1 and -2 exceeded entries by 75 and 60 fish, respectively, in 1993 and all of the fish were moving downstream prior to leaving the fishway. At Lower Granite Dam where the fishway fence had been removed prior to the 1993 migration season, exits by salmon exceeded entries by 50 at NPE-1, but entries exceeded exits by 75 at NPE-2. The fishway fences tested in 1992 and 1993 did not reduce exits from the fishway, indeed they probably increased exits, because large numbers of the fish move up and down the collection channels before proceeding up the ladders and over the dams.

In 1993, 251 steelhead were trapped at John Day Dam in July and early August, and 633 were trapped in the September-early November period, outfitted with transmitters and released in the bottom of the south shore ladder. Seventeen of the 251 steelhead released in July and August were recorded in the John Day River, 122 were recorded as

they passed over McNary Dam, and 83 (33%) were recorded passing the tailrace receiver at Ice Harbor Dam in the Snake River. Sixty-four tagged steelhead moved upstream and were recaptured at the Lower Granite adult trap, mostly in the fall of 1993, but only 40 were recorded as passing through the top of the ladder at the dam. The difference between numbers recaptured in the trap and numbers recorded passing out the top of the ladder was partially due to the loss of transmitters between John Day and Lower Granite dams. Eight of the fish released in July eventually entered the Clearwater River, and 27 migrated up the Snake River past the receiver near Asotin.

Of the 633 steelhead released with transmitters in the fall of 1993 at John Day Dam, 90 were recorded entering the John Day River, 325 were recorded passing over McNary Dam, and 249 (39%) were recorded passing the tailrace receiver at Ice Harbor Dam in the Snake River. At Lower Granite Dam, 225 (36%) were recorded passing through the top of the ladder, and 260 (41%) of the tagged fish were recaptured in the adult trap, with the difference in numbers of fish recorded or recaptured due partially to loss of transmitters. Eighty-seven of the steelhead released in the fall with transmitters eventually were recorded entering the Clearwater River and 104 migrated up the Snake River past the receiver near Asotin.

In 1993, a smaller percentage of the steelhead with transmitters were reported as being caught by anglers compared to the reported catches in 1991 and 1992 (27% in the Snake River basin). The reported catch in 1993 was 91fish (10.3% of the 884 fish released) in the Snake River basin, and 112 fish (12.7%) in the rivers and streams outside the Snake River basin.

Migration rates of steelhead released with transmitters at John Day Dam in 1993 were assessed from John Day Dam upstream into the Snake River, past the Snake River dams and through their reservoirs, and in the free flowing rivers upstream from the reservoirs. Steelhead migrating up the ladder at John Day Dam following release in the summer or fall took 0.9 and 0.2 d, respectively, to pass over the dam. Median travel times from the top of John Day Dam to the top of McNary Dam were about 4 d, and from McNary Dam to the tailrace at Ice Harbor Dam 2.5 and 3.0 d, respectively, for the fish released in summer versus fall. Median passage times at the lower Snake River dams in 1993 ranged from 0.3 to 1.0 d, a little faster at some dams than in 1992 and 1991, for steelhead that migrated through the lower Snake River in the fall of 1993. At Ice Harbor Dam, the median passage time for fish ascending the south shore ladder was 0.3 d longer when the trap was in operation versus when it was not (0.1 d). Passage rates for both summer and fall released steelhead migrating through the reservoirs in the fall were similar (22 to 36 km/d, based on median days to pass) in the two Columbia River reservoirs and the three lowest Snake River reservoirs. The rates of migration through Lower Granite Reservoir into the Clearwater River were slower (4-5 km/d) than those for the downstream reservoirs, as has been reported for prior years. Migration rates in the

free-flowing rivers upstream from Lower Granite Reservoir ranged from about 1 to 18 km/d.

The results have been consistent from three years of tests to assess the effects of reducing discharge from the three upper dams to near zero at night during the fall on the migration of steelhead, and we do not see any clear evidence that discharge from the dams at night affect fish movements. In 1991, the first of four two-week test periods began in mid September when river temperatures had started to decline and adequate numbers of steelhead were moving into the Snake River. The first period was a zero flow period followed by one with normal flow, then one with zero flow, and finally the last one with normal flow. In general, migration rates and the percentage of tagged steelhead counted or recaptured at the upstream dams was highest for the steelhead released at the start of the second period with normal flow at night. Steelhead released in the first and third periods with zero flow at night migrated at similar rates that were almost as fast as the fish in the second period. Steelhead in the fourth period migrated much slower than fish in the earlier periods, despite having normal flow at night. A similar pattern of movement occurred in 1992 with five groups of steelhead released starting earlier in September and the order of zero and normal flow alternated from that in 1991 (normal flow first). Although some of the differences in migration rates and proportions moving upstream during the two-week periods were significant, we doubt the differences were a result of flow at night. River temperatures were declining throughout the duration of the test and may have been the major factor affecting migration rates. We suspect that during the first two-week period temperatures had declined enough that fish began migrating up the river, but were still too high for maximum migration rates. During the middle periods, temperatures were ideal for rapid upstream movement, and by the fourth periods, temperatures and time of season induced some steelhead to begin their overwintering behavior of holding somewhere in the lower Snake River. In 1993, the zero-flow test was continued as in past years, but the nighttime flows for the first two-week period were near zero, as in 1991, followed by normal, zero, and normal flows in the remaining periods. The first period started on 6 September in 1993 and fish released during that period took longer to pass the upstream dams following release (median days of 7 to 15) than fish released in the next three periods (median days of 4 to 12), a result that was consistent with observations in 1991 and 1992. The percentages of spaghetti-loop tagged fish from the four release groups that were counted at the dams or recaptured at the Lower Granite adult trap followed a similar pattern observed in the previous two years; highest percentages for the fish released during the second and third periods and lower rates for those released during the first and fourth periods. Migration rates and percentages of steelhead counted or recaptured at the dams were similar for fish released during the second and third periods (latter part of September and early part of October) regardless of the flow at night.

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Appendix A

Flow Patterns at the Lower Snake River Dams During Spill in 1993

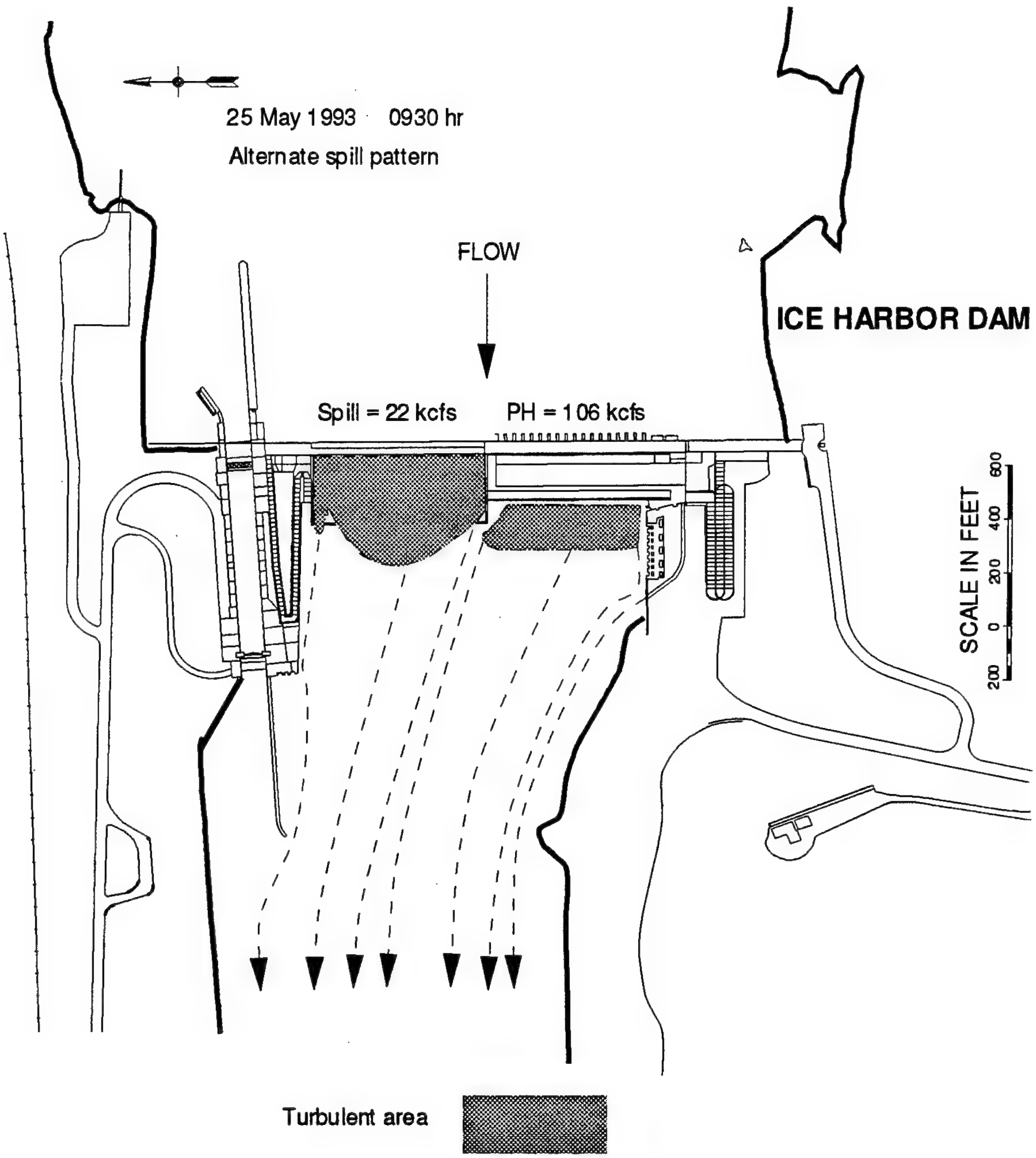

Figure A1. The alternate spill pattern at Ice Harbor Dam during low spill levels (22 kcfs) as interpreted from video tape images and notes made at the time.

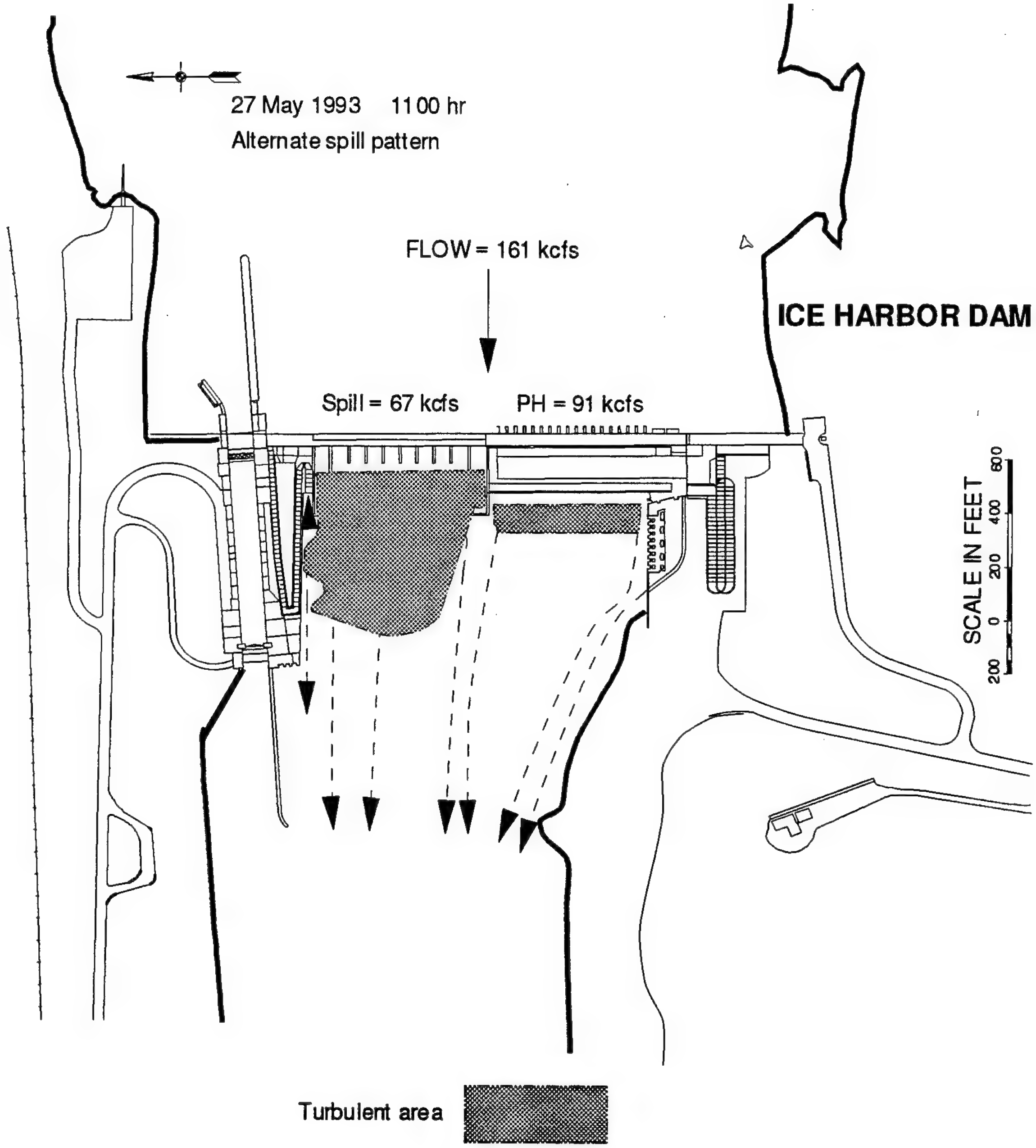

Figure A2. The alternate spill pattern at Ice Harbor Dam during medium spill levels (67 kcfs) as interpreted from video tape images and notes made at the time.

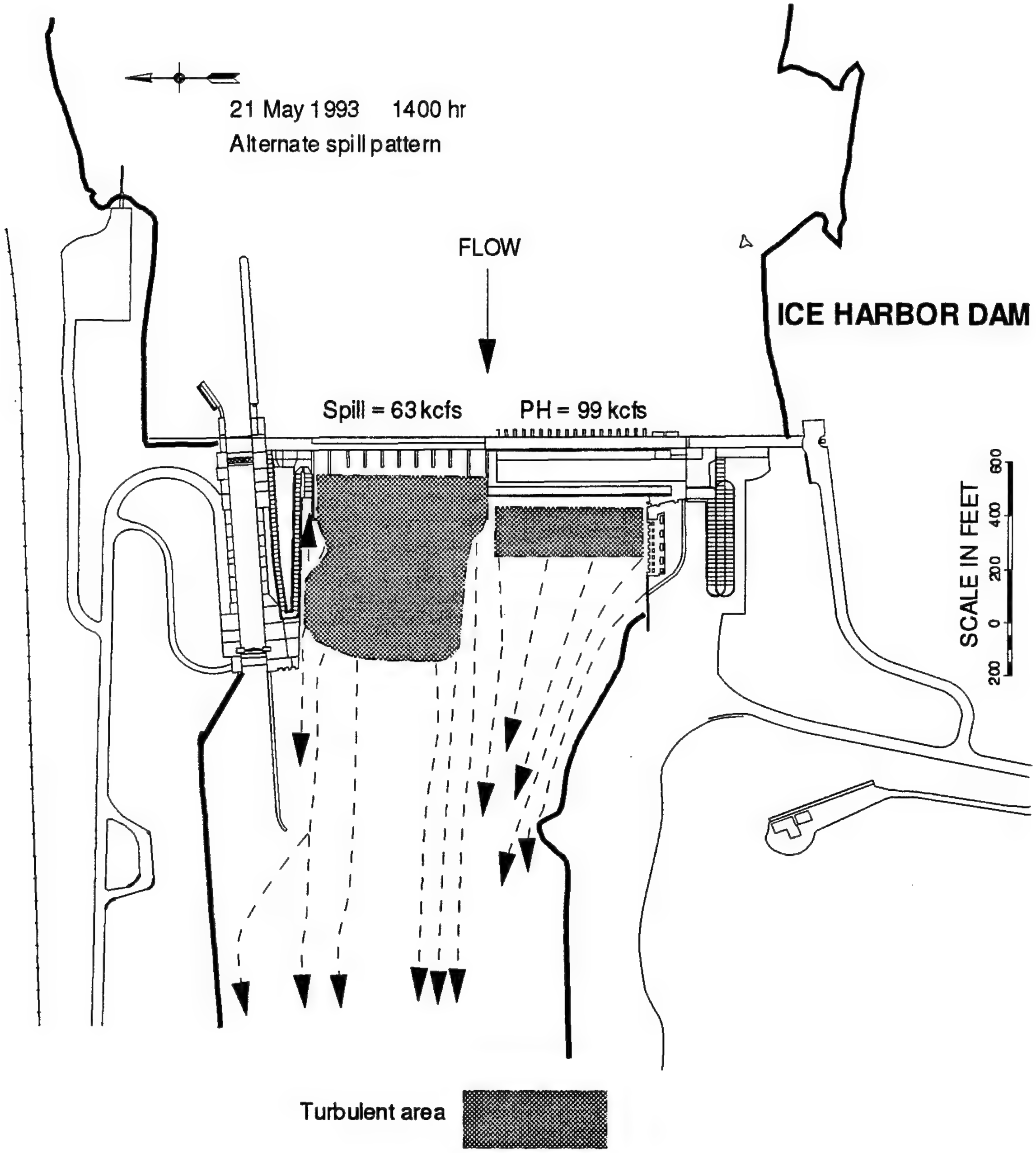

Figure A3. The regular spill pattern at Ice Harbor Dam during medium spill levels (63 kcfs) as interpreted from video tape images and notes made at the time.

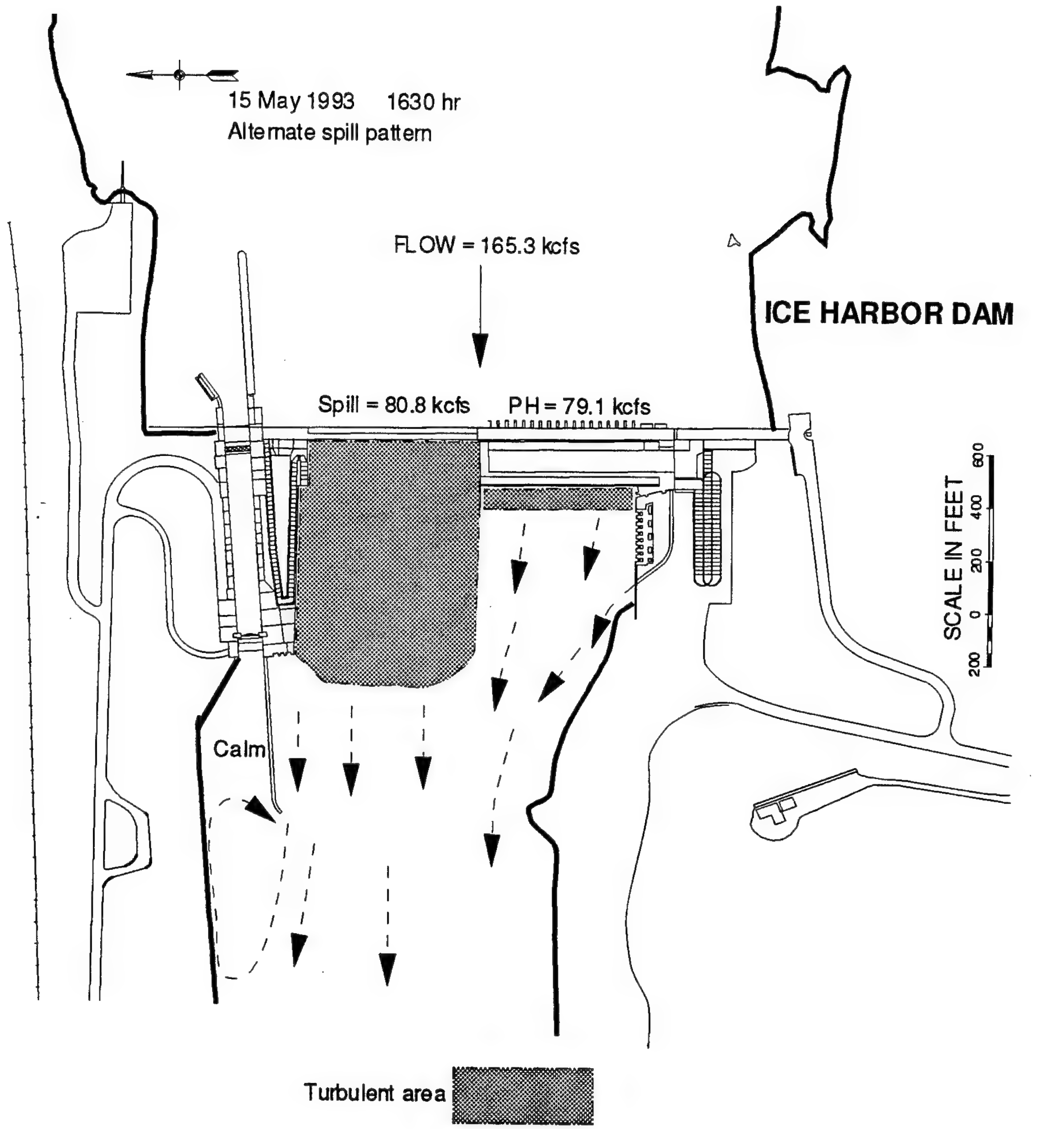

Figure A4. The alternate spill pattern at Ice Harbor Dam during high spill levels (81 kcfs) as interpreted from video tape images and notes made at the time.

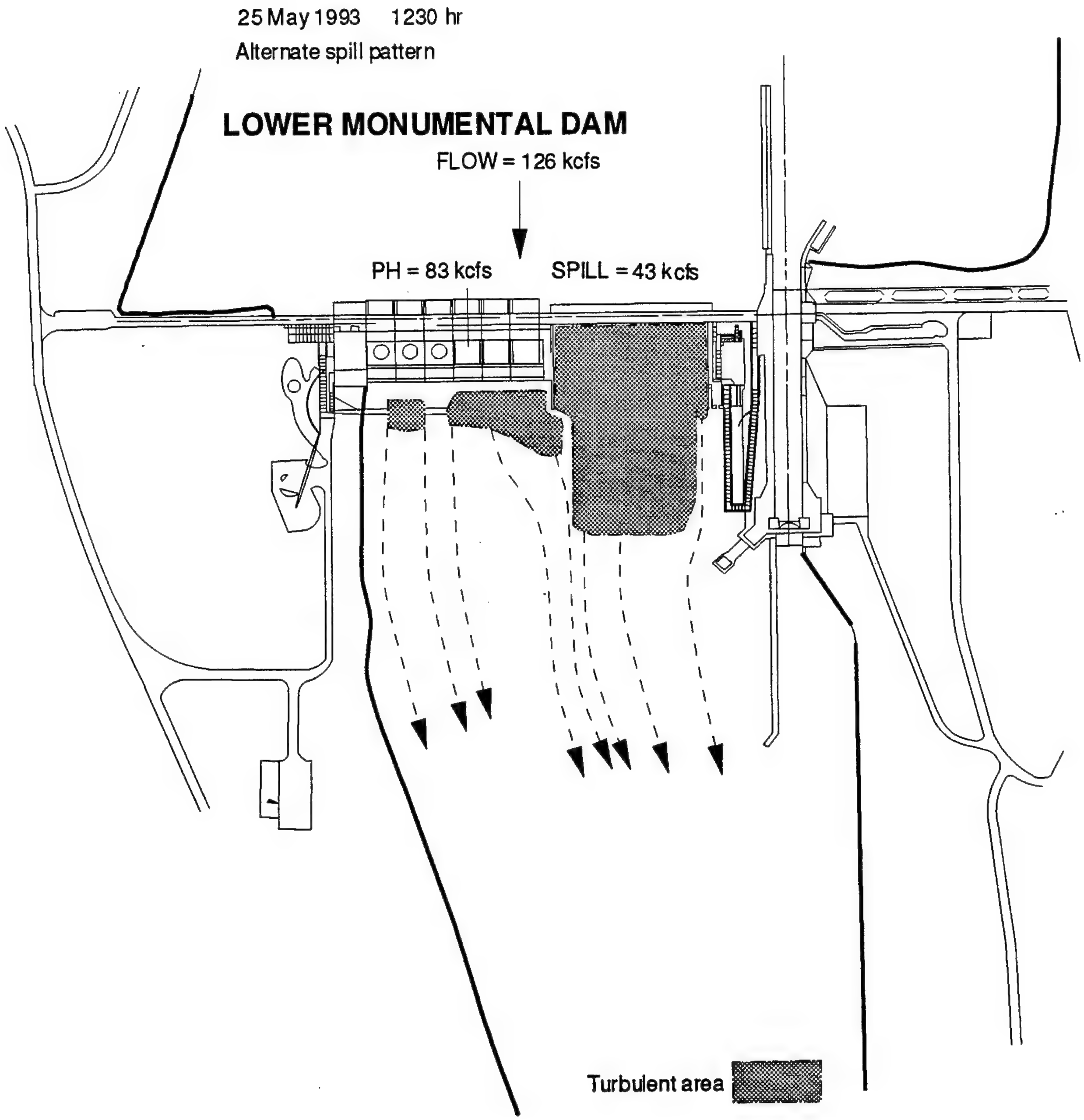

Figure A5. The alternate spill pattern at Lower Monumental Dam during low spill levels (43 kcfs) as interpreted from video tape images and notes made at the time.

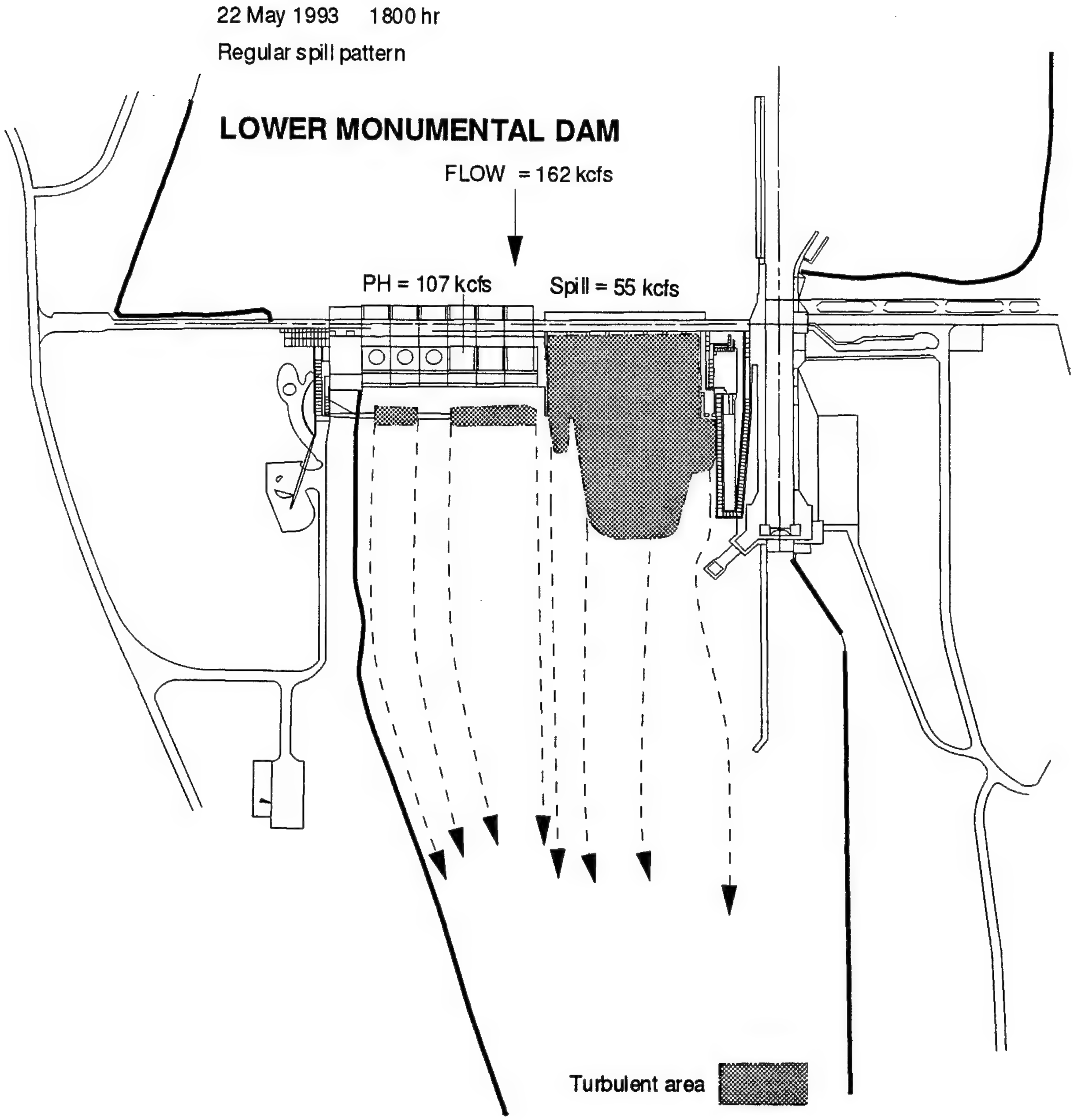

Figure A6. The regular spill pattern at Lower Monumental Dam during medium spill levels (55 kcfs) as interpreted from video tape images and notes made at the time.

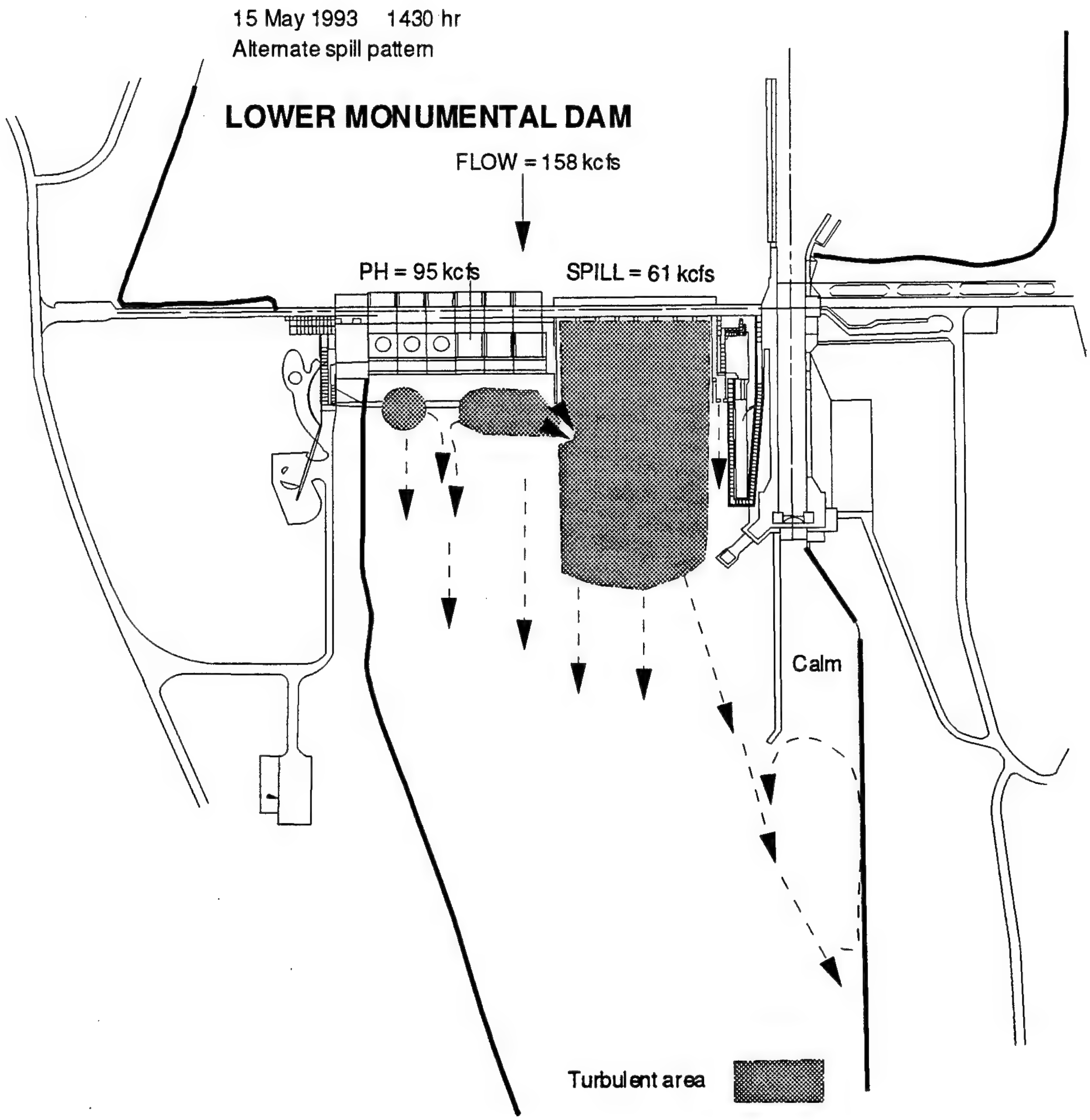

Figure A7. The alternate spill pattern at Lower Monumental Dam during high spill levels (61 kcfs) as interpreted from video tape images and notes made at the time.

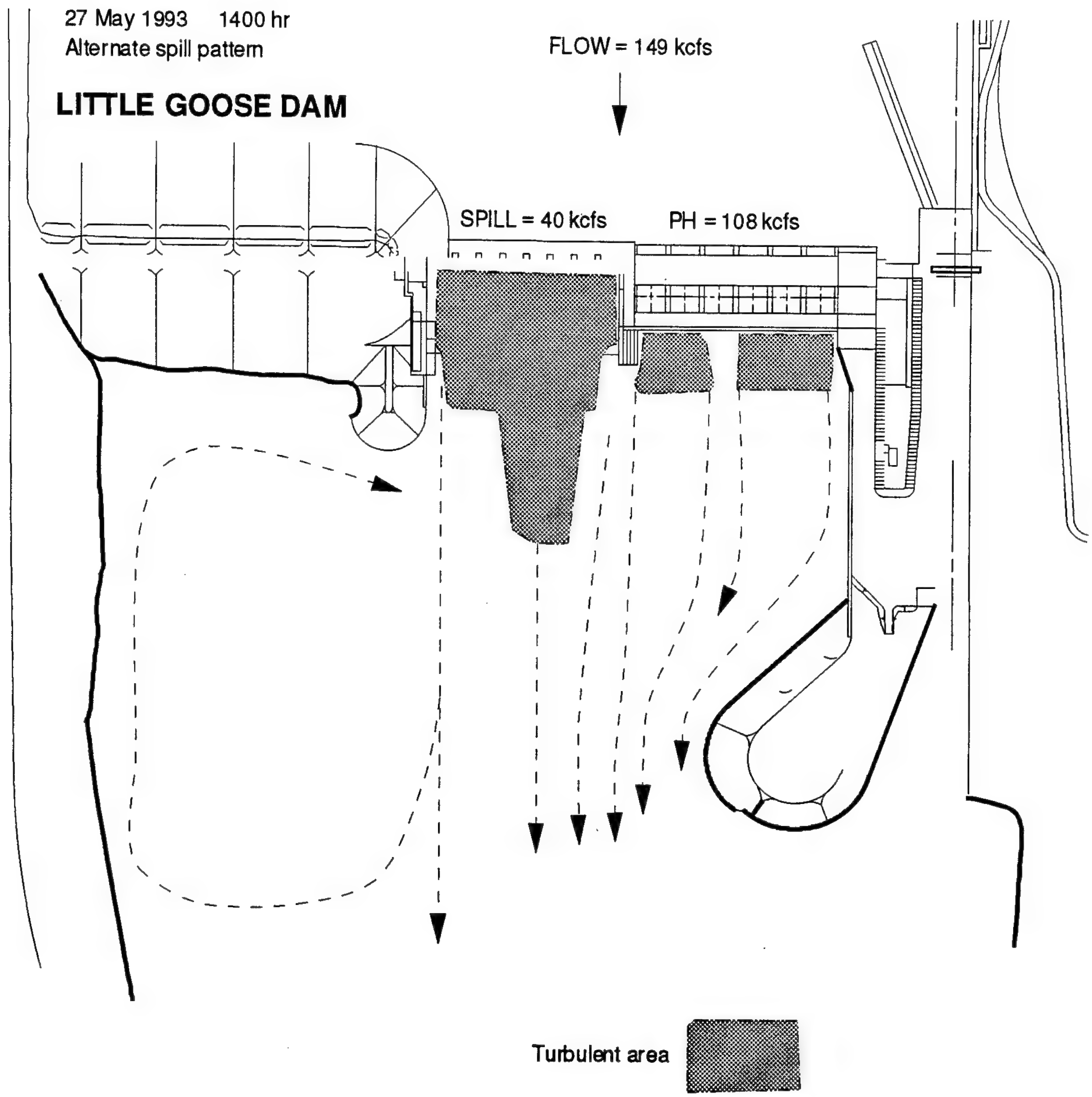

Figure A8. The alternate spill pattern at Little Goose Dam during low spill levels (40 kcfs) as interpreted from video tape images and notes made at the time.

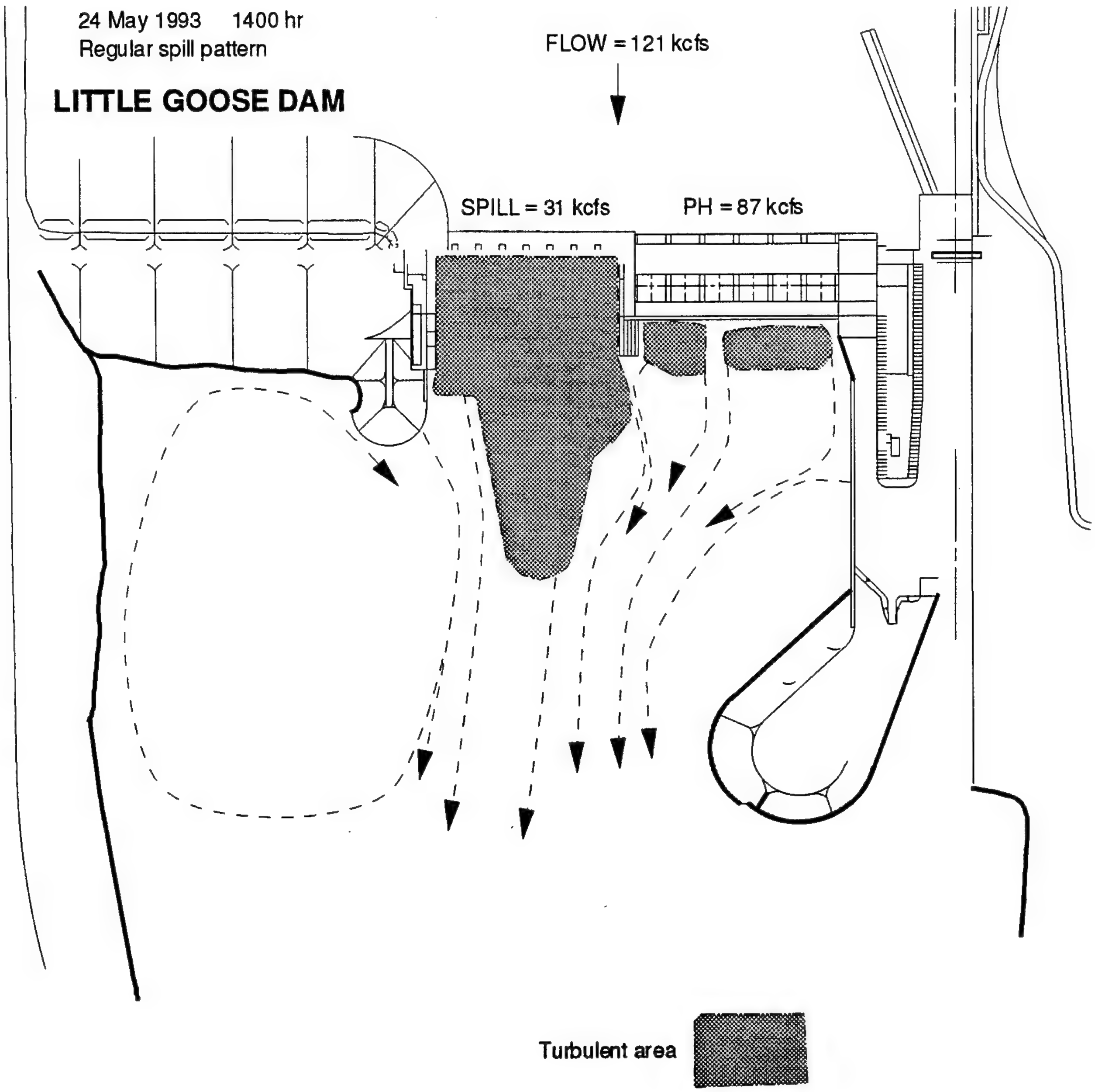

Figure A9. The regular spill pattern at Little Goose Dam during low spill levels (31 kcfs) as interpreted from video tape images and notes made at the time.

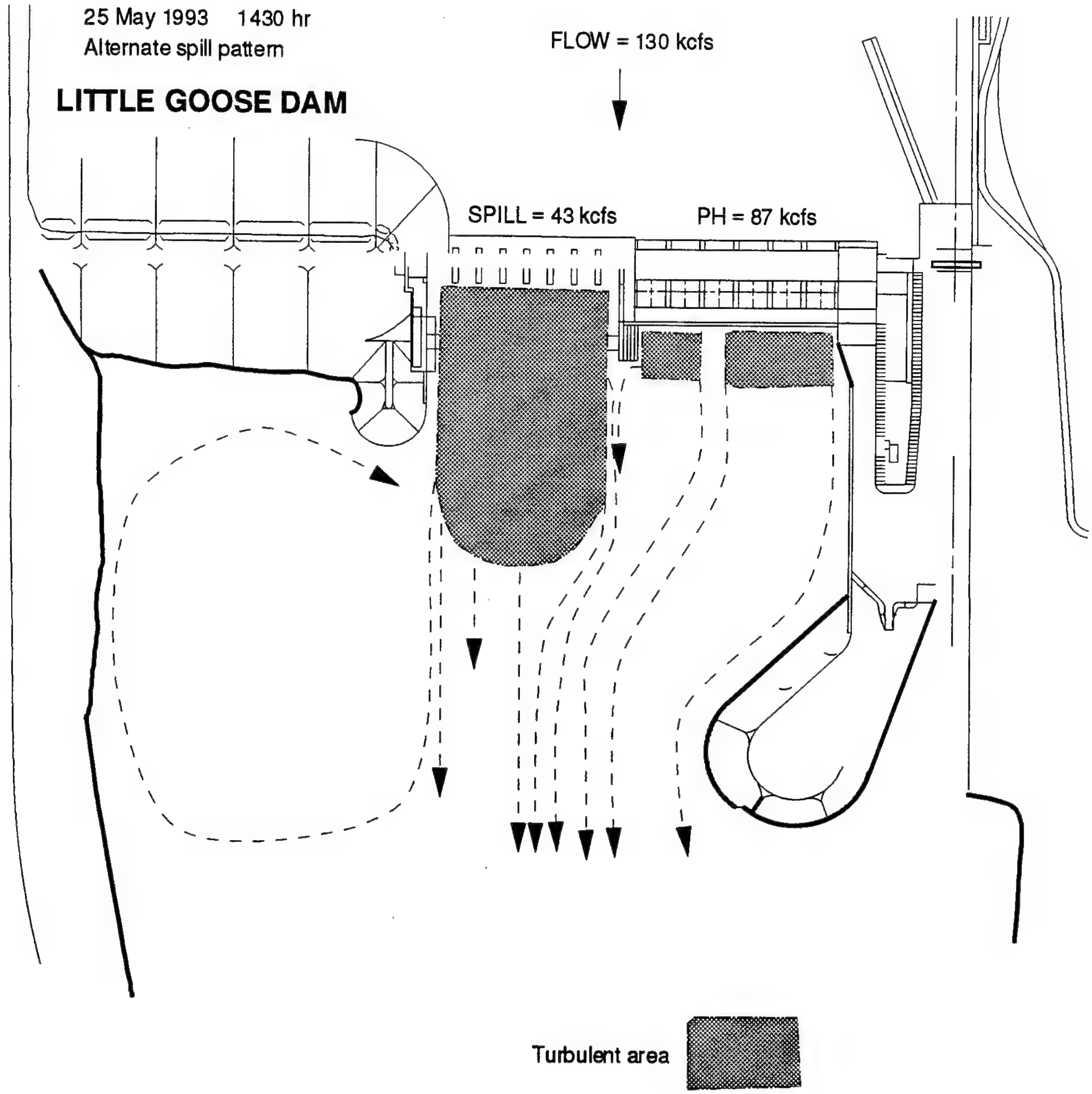

Figure A10. The alternate spill pattern at Little Goose Dam during medium spill levels (43 kcfs) as interpreted from video tape images and notes made at the time.

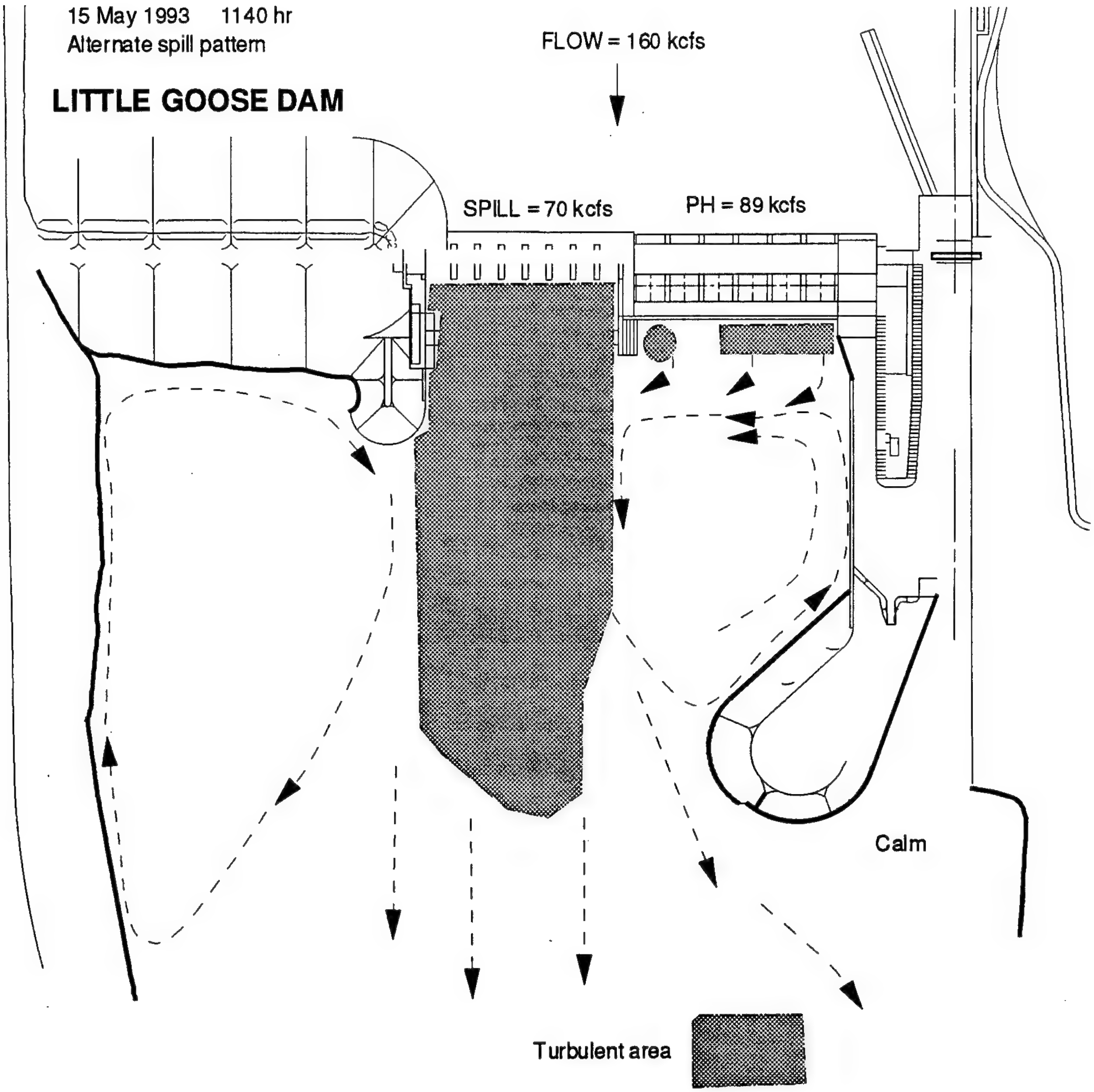

Figure A11. The alternate spill pattern at Little Goose Dam during medium spill levels (70 kcfs) as interpreted from video tape images and notes made at the time.

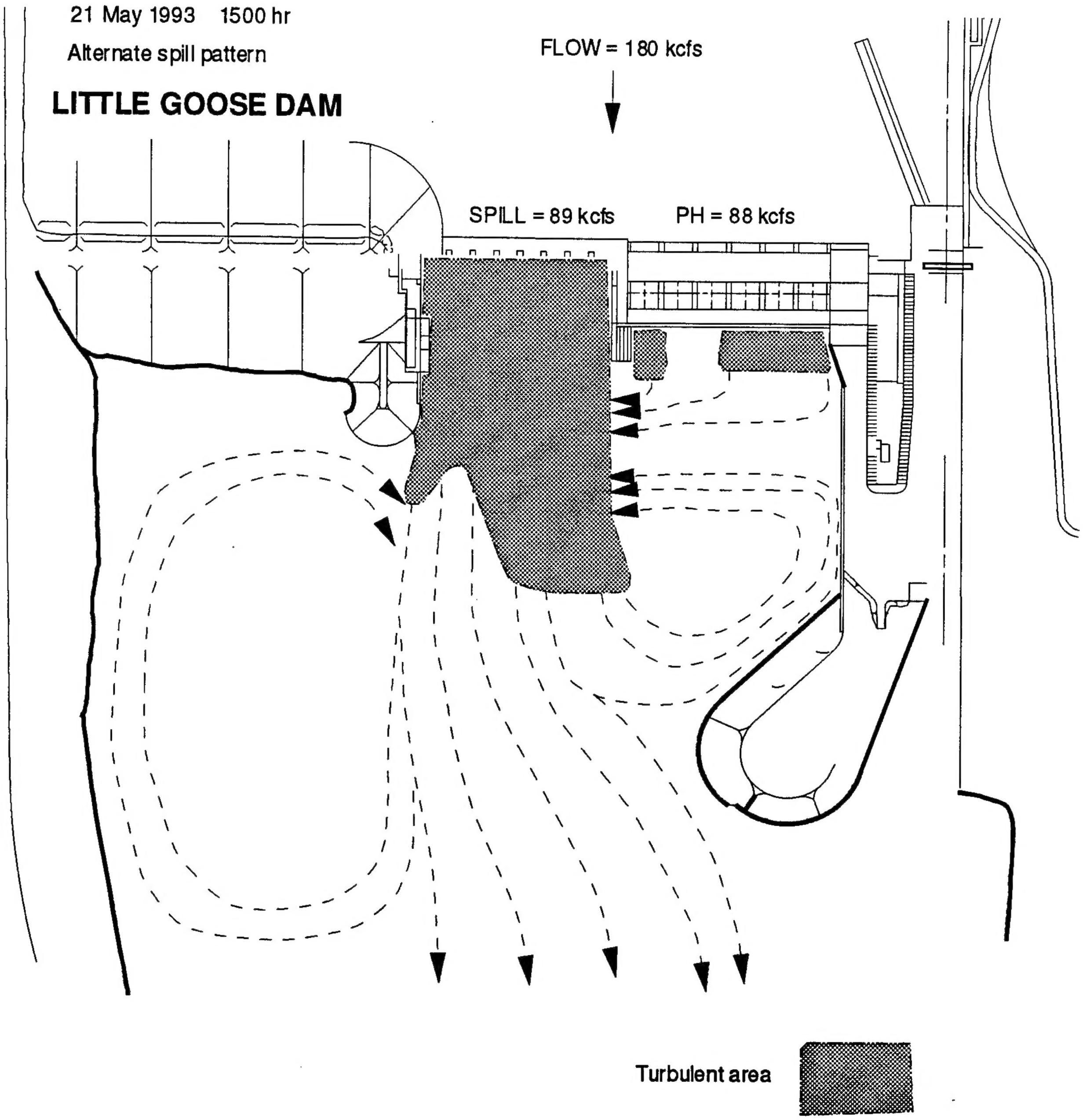

Figure A12. The alternate spill pattern at Little Goose Dam during high spill levels (89 kcfs) as interpreted from video tape images and notes made at the time.

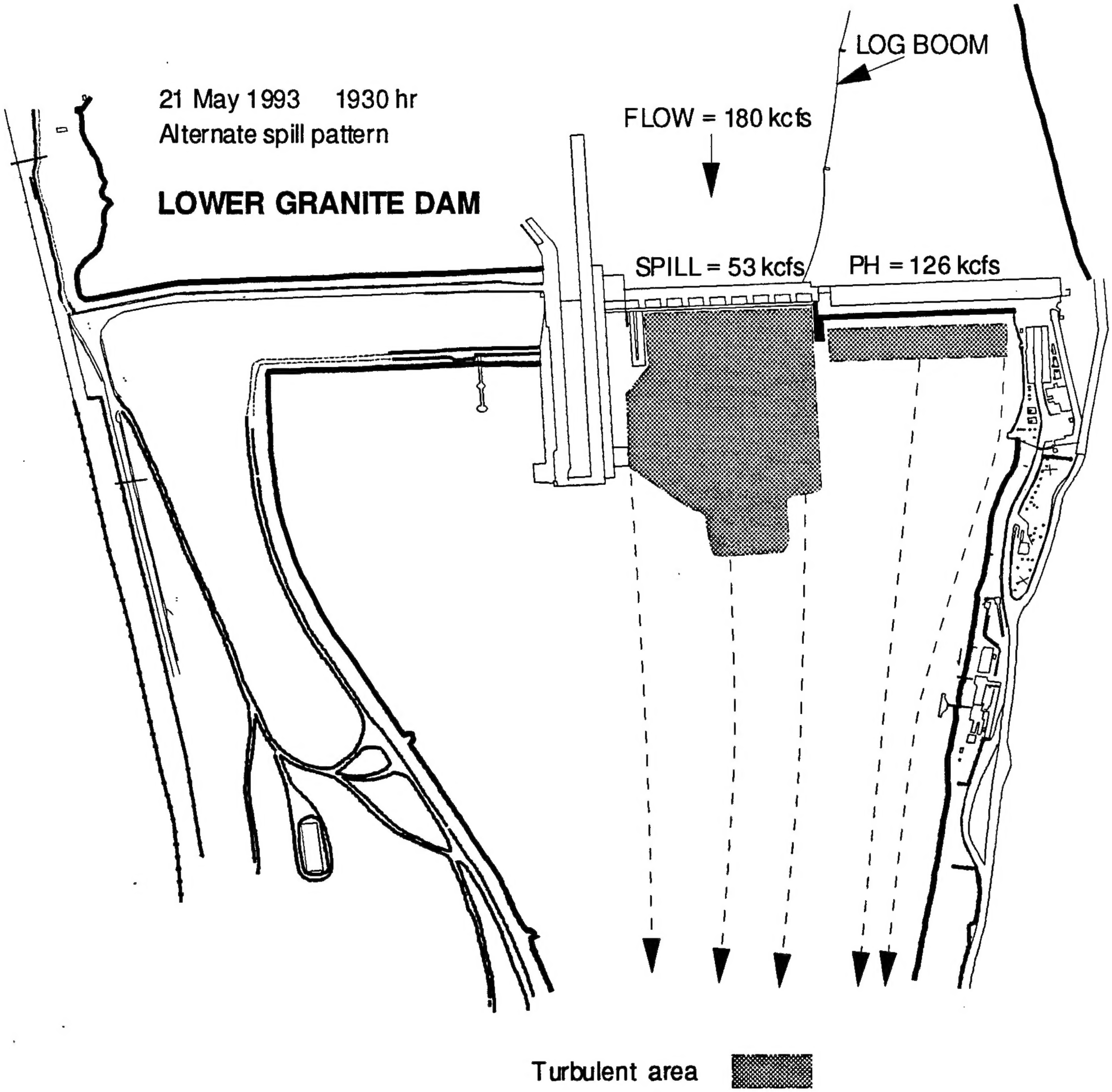

Figure A13. The alternate spill pattern at Lower Granite Dam during medium spill levels (53 kcfs) as interpreted from video tape images and notes made at the time.

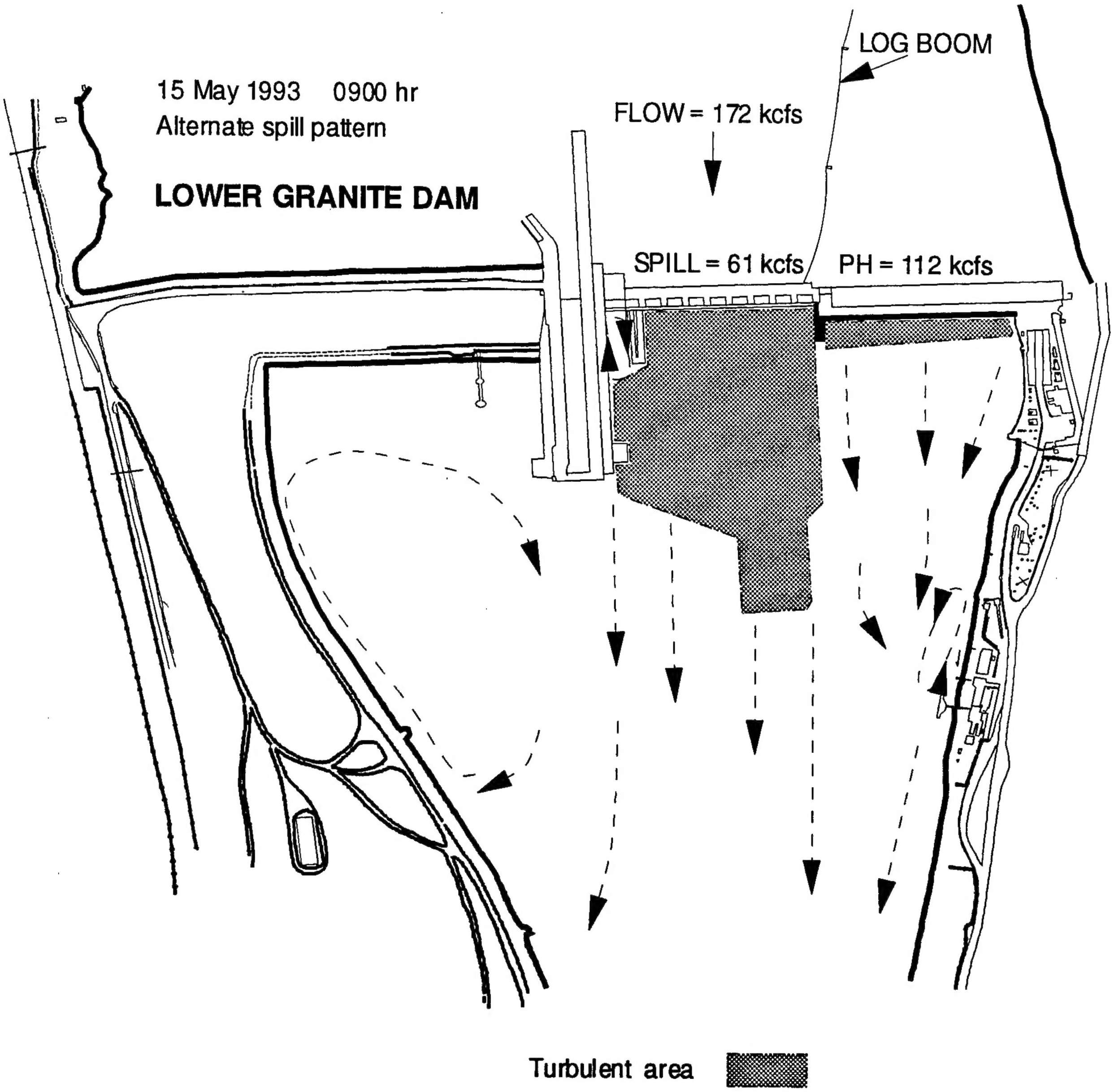

Figure A14. The alternate spill pattern at Lower Granite Dam during medium spill levels (61 kcfs) as interpreted from video tape images and notes made at the time.

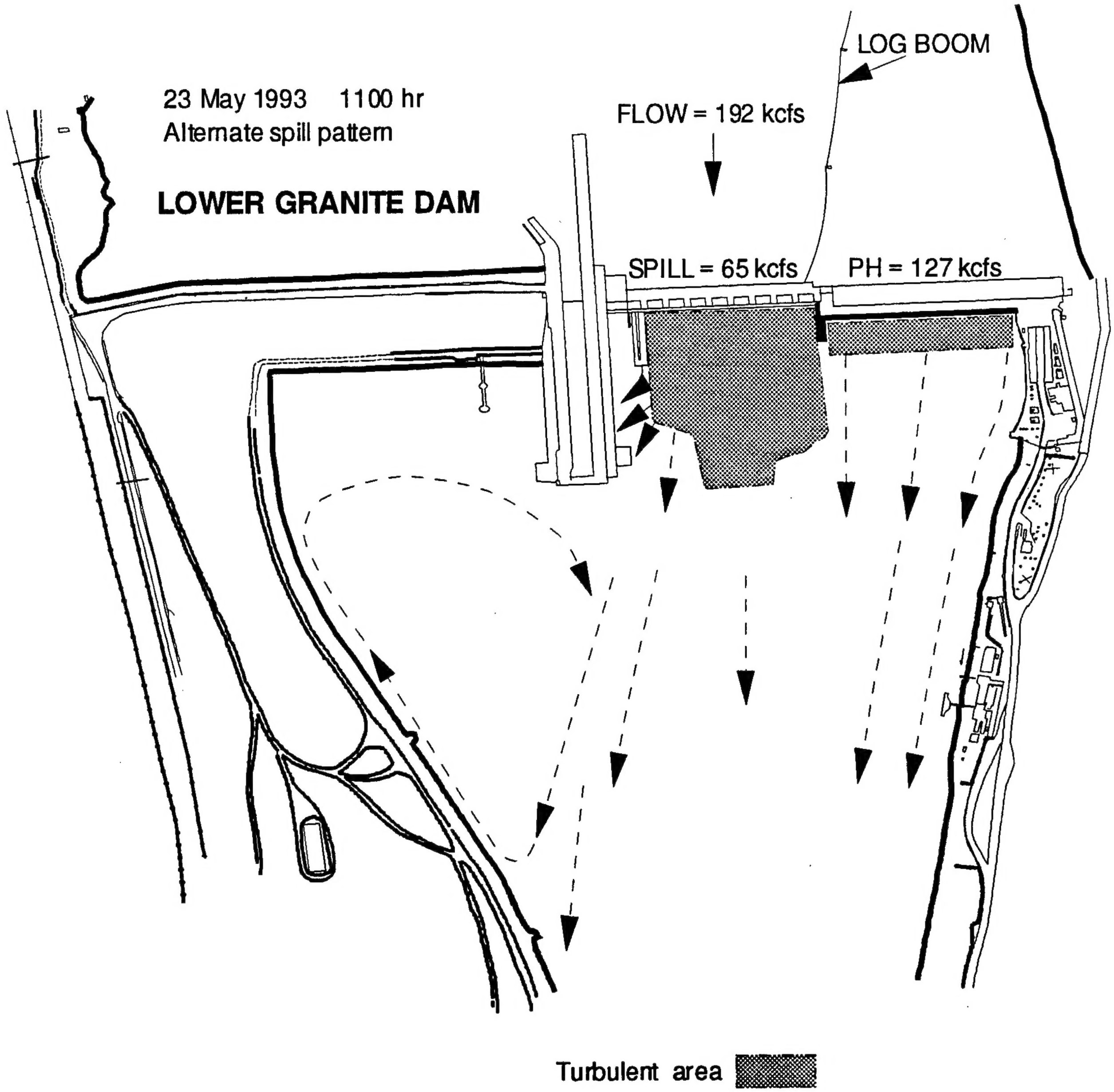

Figure A15. The alternate spill pattern at Lower Granite Dam during medium spill levels (65 kcfs) as interpreted from video tape images and notes made at the time.